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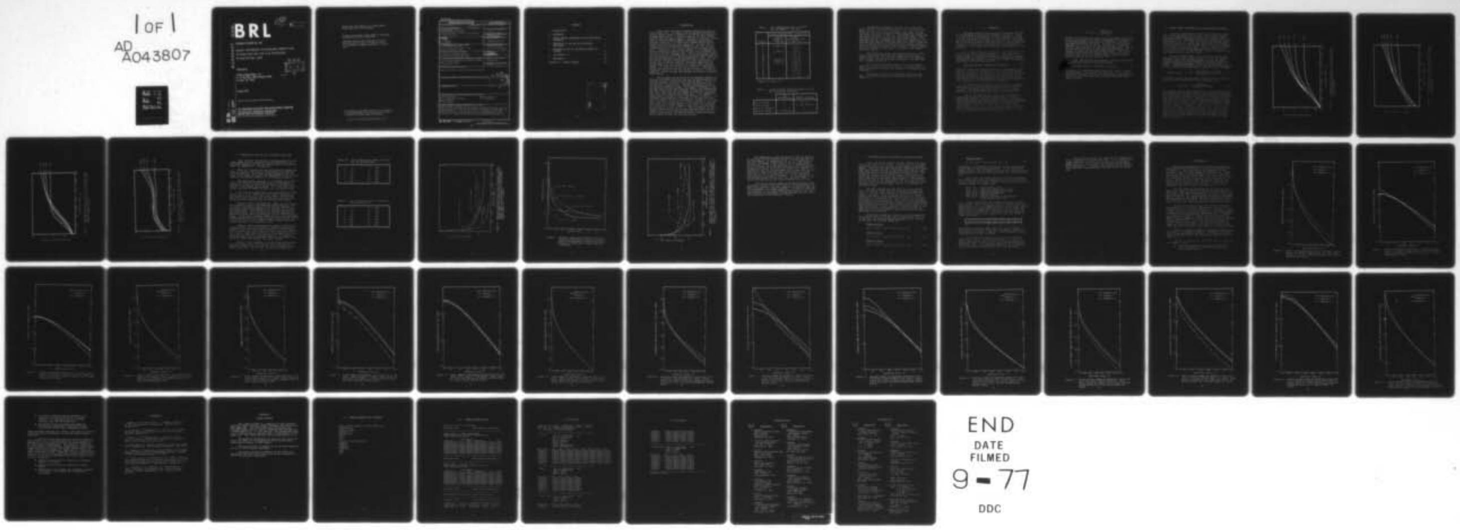

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CONTRACT REPORT NO. 345

ENERGY DEPENDENT AIR/GROUND CORRECTION FACTORS FOR THE ATR (AIR TRANSPORT OF RADIATION) CODE

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Energy dependent air/ground correction factors were generated by the use of two dimensional radiation transport calculations for neutrons, secondary gamma rays and prompt gamma rays. The correction factors were parameterized by least squares curve fitting techniques and the results incorporated into Version 4 of the ATR (Air Transport of Radiation) code to produce an ATR Version 4.1.

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CONTENTS

1. INTRODUCTION

This report describes the work performed at Science Applications, Inc., to improve the air/ground interface correction factors found in Version 4 of the ATR (Air Transport of Radiation) code[1]. Previous versions of ATR[2,3] had rather simplistic models based on the work of French[5] which does not involve results based on transport calculations. Versions 3 and 4[4,1] of ATR contain parameterized results based on calculations by Pace, et al.[6], in which only a fission and a 14 MeV neutron source were used and thus the parameterization in ATR is only weakly source energy dependent. Concurrently with another effort[7], two-dimensional adjoint radiation transport calculations were performed with the use of the DOT computer code. These calculations formed the data base for the TWEDEE (Tactical Nuclear Weapon Edit of Dose in Endoatmospheric - Earth Environment) code. This code was used to generate revised ATR correction factors for the air/ground interface corresponding to those monoenergetic groups used in ATR for neutrons, secondary gamma rays and promps gamma rays for various burst heights and horizontal ranges. It should be noted that in addition to improved air/ground correction factors for neutron sources, this effort represents the first time that correction factors in ATR for gamma ray sources (prompt and delayed) are based on transport calculations.

The air over ground radiation environments computed by Pace and the TWEDEE data base are the two most extensive sets of data available which have utilized the ENDF-IV cross section evaluations, and which have received acceptance and utilization by the industry. Besides differences in source and receiver parameter ranges, the biggest difference in the two data sets is the type of ground used in the computations. The Pace calculations utilized what is referred to as Nevada Test Site (NTS) soil and the TWEDEE data base was generated with a dry area averaged West German soil. The elemental constituents of these two soils are provided in Table I. The different concentrations of hydrogen in the two soils will have the largest effect on the radiation transport. In a recent study of the sensitivity of various effects to the radiation dose from nuclear weapons it was shown that a reasonable variation in water content could result in differences in the dose by as much as 50%[7]. Thus in addition to the improved capability to treat source spectrum variation and to correct for the air-ground perturbation for photon sources using transport data, the new air ground correction factors also provide another soil hydrogen content.

Table I. Soil Compositions Used by Pace[6] and the TWEDEE[7] Data Base

Element	Atomic Concentration (atoms/b-cm)	
	Pace[6] Nevada Soil (ATR 4)	TWEDEE[7] West German Soil (ATR 4.1)
H	9.7656(-3)*	1.10(-3)
C		1.02(-3)
O	3.4790(-2)	1.90(-2)
Na		9.91(-5)
Mg		1.61(-4)
Al	4.8828(-3)	4.36(-3)
Si	1.1597(-2)	6.83(-3)
K		3.08(-4)
Ca		9.56(-4)
Tl		8.82(-6)
Mn		1.15(-6)
Fe		1.75(-4)

*Read as 9.7656×10^{-3}

Table II. Source-Detector Parameter Ranges for the Air Over Ground Data Bases

	Pace Calculations	TWEDEE Data Base
Source Energy	2	15 - 18
Source Height	4	14 (see Table IV)
Detector Response	2	2
Detector Height	4 selected	1

As mentioned previously, the two sets of air over ground radiation environment data bases have different parameter sets for the source and target. The number of variables for the source energy and height, and target response and height are given in Table II. The TWEDEE data emphasizes the source variation but has only one target height. The Pace data has more information on the target response. The work reported here, concerns the efforts to combine these two different and somewhat incomplete data bases into a form suitable to provide correction factors for the ground perturbation for all source spectra, source heights, target responses and target heights encountered in the analysis of weapon radiation effects.

The correction factors were parameterized as a function of horizontal range for each energy group and each source height, and the resulting coefficients are assembled into Version 4 of ATR resulting in Version 4.1 of ATR. Version 4 remains unaltered.

For the delayed photons there is no source energy dependence since the source structure is inherently build in, thus the correction factors only depend on the geometry configuration.

This report describes the improved air/ground data base, its parameterization and subsequent results of ATR Version 4.1.

2. BACKGROUND

The basic quantity constituting the data base for ATR is the homogeneous infinite air fluence $\phi_0(E_S, E_D, \rho, \mu)$ which is a function of source energy E_S, detector energy E_D, range ρ in units of gm/cm^2 and angle μ at the detector. By proper scaling techniques the air density variations can be accounted for at arbitrary geometry configurations, but other models are necessary to correct for the air-ground interface when the source and/or the target are within about one kilometer of the ground.

The initial versions of ATR[2,3] used variations of the first-last collision model of French[5]. From this model factors $F(H_S)$ and $F(H_T)$ are derived for source height H_S and target height H_T, respectively, which are treated as independent perturbation factors to correct the infinite air results according to the following equation:

$$\phi(E_S, E_D, \rho, H_S, H_T) = \phi_0(E_S, E_D, \rho) F(H_S) F(S_T) \tag{1}$$

where the correction factors introduced two independent variables H_S, H_T and the perturbation in the angular dependence was not considered. The first-last collision model estimates $F(H_S)$ by calculating the effective fraction of first collisions about the source as a function of source altitude, H_S. The function $F(H_T)$ is determined by calculating the number of last collisions in the vicinity of the target.

In addition to this model, for neutrons and secondary gamma rays, the correction factors were modified by Straker's two-dimensional transport calculations[8] of dose versus distance. For prompt gamma rays only a slightly modified first-last collision model exists for all ATR versions[2].

Pace at Oak Ridge National Laboratory performed two-dimensional radiation transport calculations in air-over-ground geometries[6] with the DOT-III code for 14 MeV neutron source and a weaponized fission source. The data for neutrons and secondary gamma rays was reported for four different source heights: 1, 50, 100, 300 m, a set of target heights to approximately 1300 m and a set of horizontal ranges to about 1500 m. This data was obtained and the following correction ratio was parameterized within ATR Version 4:[1,4]

$$C(R,H_S,H_T) = \frac{D_G(R,H_S,H_T)}{D_A(R,H_S,H_T)} \qquad (2)$$

where R is the horizontal range, H_S is the source height, H_T is the target height, $D_G(R,H_S,H_T)$ represents the Pace Henderson tissue response and $D_A(R,H_S,H_T)$ represents the corresponding ATR infinite air data. The data is source energy dependent only to the extent that two sources, 14 MeV and fission, were used when the data base was generated. The correction factors are used to multiply the ATR infinite air results to obtain the air-over-ground effects. For source energies below 5 MeV the fission source correction factors are used, and for source energies above 5 MeV the 14 MeV source correction factors are used.[1,4]

Thus, ATR Version 3 and Version 4 generate fluence and dose quantities described by the following:

$$\phi(E_S,E_D,R,H_S,H_T) = C(R,H_S,H_T)\ \phi_0(E_S,E_D,\rho) \qquad (3)$$

Of course, the horizontal range R and slant range ρ are related because of the geometry configuration. Also, inherent in the above equation is that the source energy dependence is limited to the 5 MeV cross over selection constraint previously described.

3. SOURCE ENERGY DEPENDENCE OF AIR-OVER-GROUND INTERFACE

A further improvement of ATR's air-over-ground interface correction factors is obtained by utilizing a computer code called TWEDEE (Tactical Nuclear Edit of Dose in Endo-atmospheric-Earth Environment) which was developed at Science Applications, Inc..[7] This code folds source energy importances and sources for prompt and delayed dose for detectors located at 1.75 m from the ground using a data base generated with the DOT code in ajoint mode. The soil composition used in the Pace[6] forward-mode DOT calculations and the soil composition used for the DOT/TWEDEE[7] adjoint transport/data base generation are listed in Table I.

Using the TWEDEE code, it is possible to obtain the following dose values: $D_T(E_S, R, H_S, H_T = 1.75\text{ m})$ for neutrons, secondary gamma rays and prompt gamma rays for each mono-energetic source band corresponding to the ATR structure for a set of horizontal ranges to 1300 m and source heights to 1100 m. Corresponding infinite air dose values are calculated by ATR as well, and the following correction ratio is formed:

$$C_T(E_S, R, H_S, H_T = 1.75\text{ m}) = \frac{D_T(E_S, R, H_S, H_T = 1.75\text{ m})}{D_A(E_S, R, H_S, H_T = 1.75\text{ m})} \qquad (4)$$

In order to account for the target height variation, the correction factor is multiplied by the following ratio:

$$P(R, H_S, H_T) = \frac{C(R, H_S, H_T)}{C(R, H_S, H_T = 1.75\text{ m})} \qquad (5)$$

For neutrons and secondary gamma rays this perturbation factor is available from the Pace data.[6] Note that the correction for target height is based on data from calculations performed with a different hydrogen concentration in the soil than the data base used for Eq. (4). Although this procedure is less than ideal, it is felt to be more reliable than other schemes such as a last collision model. Again, the attempt is to use the information available to produce the most accurate model. Figures 1 through 4 represent examples of this perturbation factor for neutrons and secondary gamma rays, one figure for each source. There perturbation factors are used to correct for the target height variation for neutrons and secondary gamma rays. For the prompt and the delayed gamma rays the first-last collision model[2] is used to correct for target height variations.

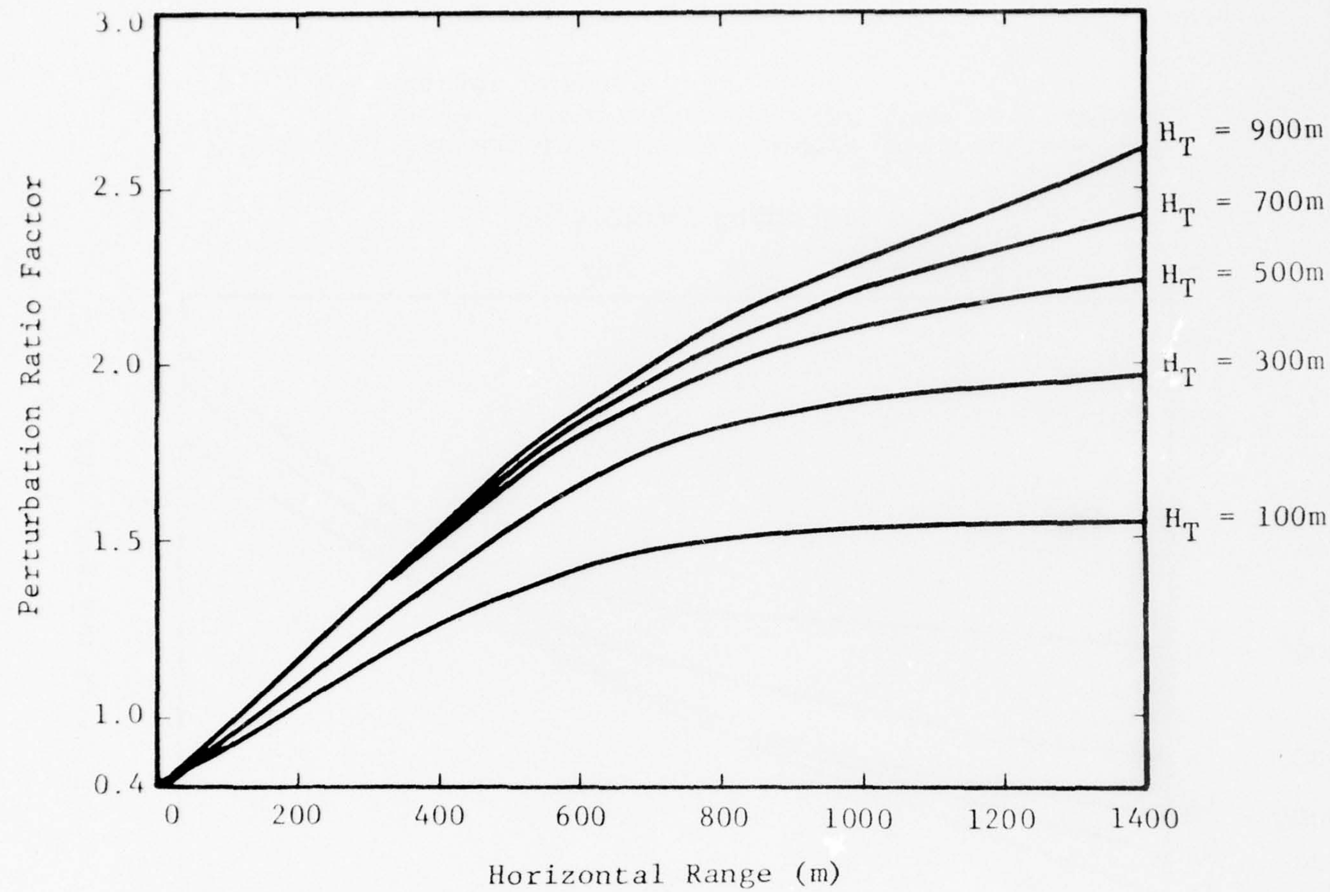

Figure 1. Perturbation ratio factors for neutrons for a fission neutron source at 100m and various target heights.

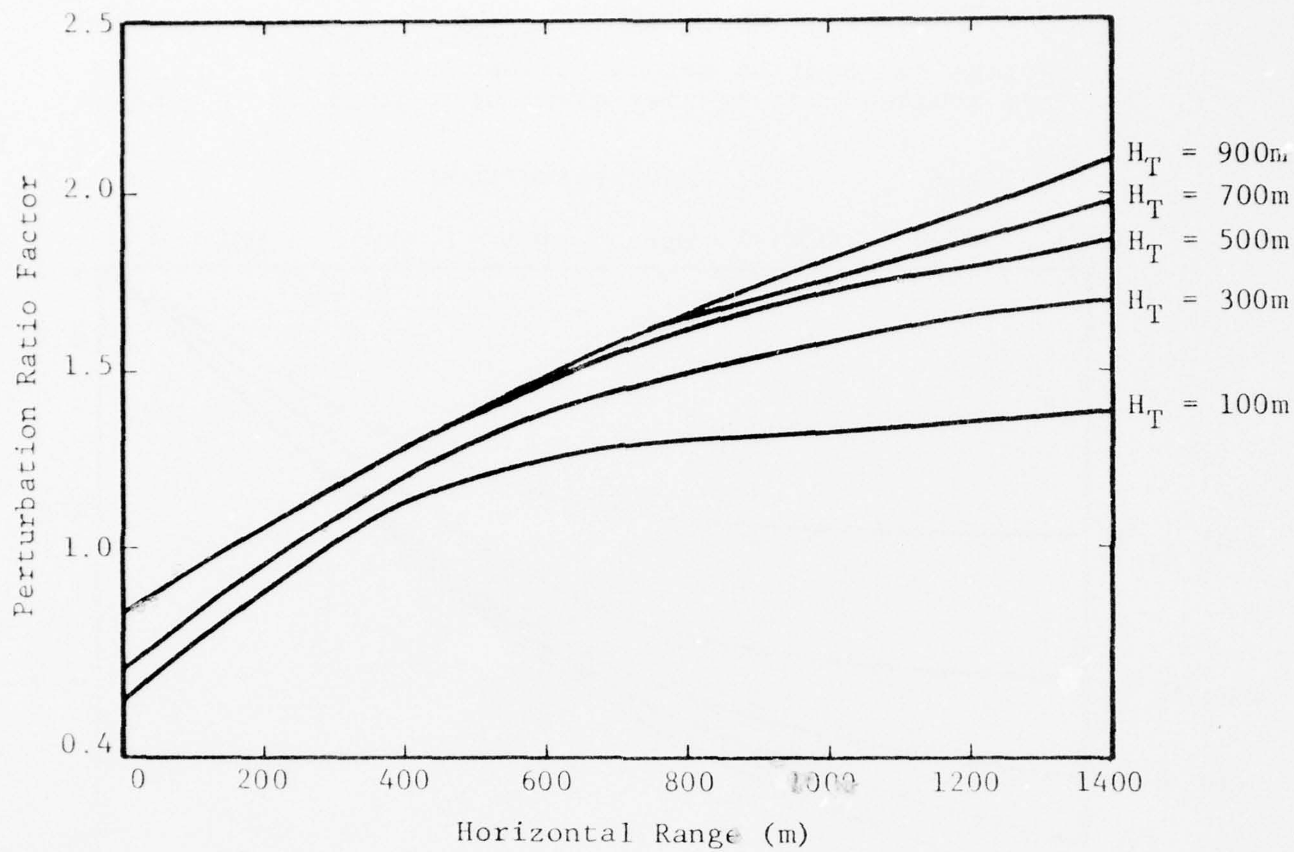

Figure 2. Perturbation ratio factors for neutrons for a 14 MeV neutron source at 100m and various target heights.

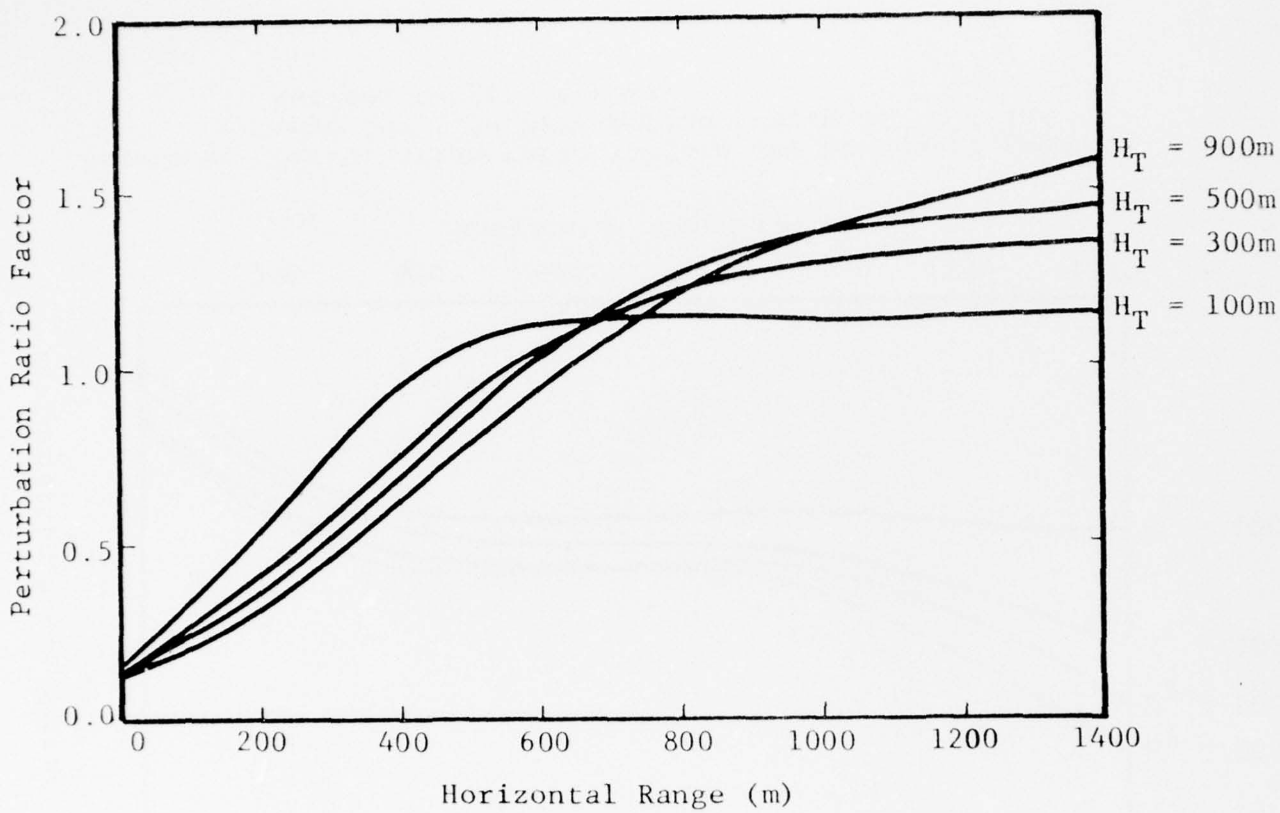

Figure 3. Perturbation ratio factors for secondary gamma rays for a fission neutron source at 100m and various target heights.

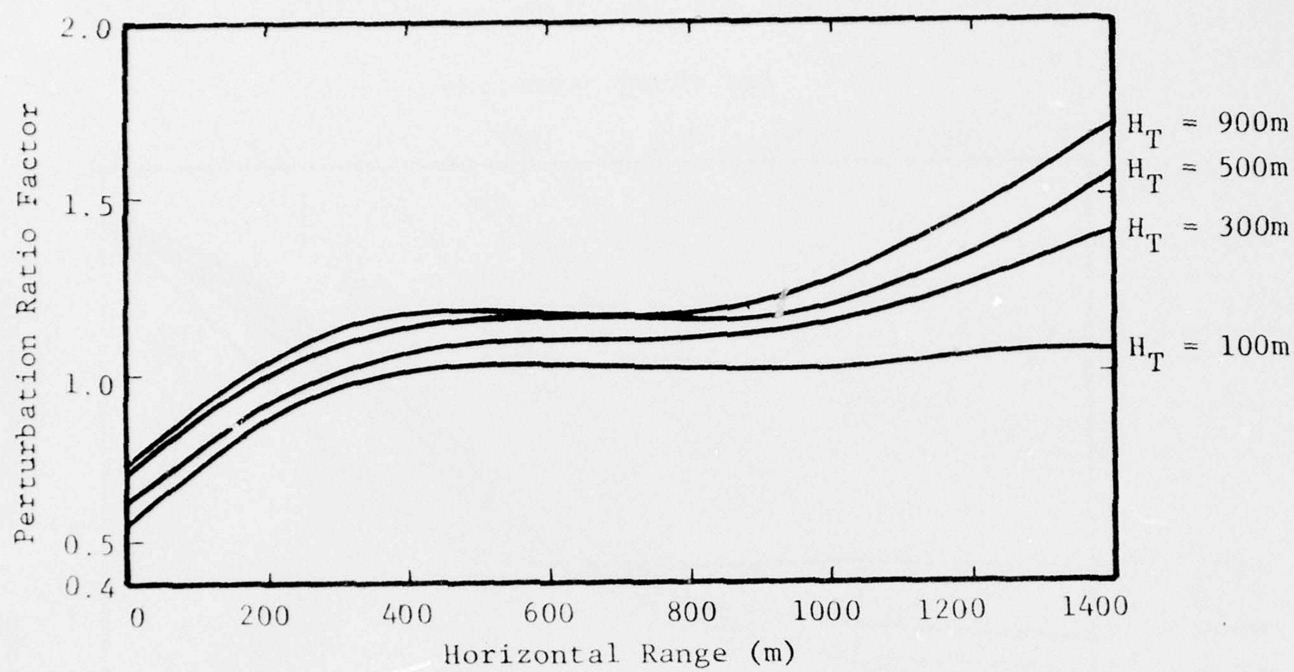

Figure 4. Perturbation ratio factors for secondary gamma rays for a 14 MeV neutron source at 100m and various target heights.

4. GENERATION OF THE NEW ATR AIR/GROUND DATA BASE

Dose responses for neutrons, secondary gamma rays and prompt gamma rays are generated from the TWEDEE code, the scattered components of each are selected and the correction ratio, C_T (Equation 4), is generated.

Table III contains the selected horizontal ranges and Table IV contains the selected source heights at which the data is generated. The choice of these parameters is dictated by the possible range of the TWEDEE data as well as the areas of anticipated structure of the correction factors.

The energy group structure in the TWEDEE code is different from that of the ATR code, thus some regrouping is necessary and some of the ATR energy groups are split into several of the TWEDEE energy groups. The total span of the energy structure of TWEDEE includes the total span of ATR.

The correction factor data base was generated by forming the ratio of the TWEDEE dose to the ATR 4 infinite air, uncorrected dose for its given source-target configuration. The neutron dose response used for the ratio was the tissue kerma and photon response was the Henderson tissue dose.

Figure 5 shows a representative sample of the new neutron correction factors for different source energies. Due to certain convergence limitations of the DOT code some of the neutron data corresponding to low energies is not available from TWEDEE. This limitation is not very serious for most applications since it occurs for source heights of 500 meters and above, for source energies of 3.35×10^{-3} MeV and below. A sensitivity analysis shows that for a typical thermonuclear source those low energy sources contribute less than 1.5% to the total. For a typical fission source those low energy sources do not contribute at all.

Figure 6 shows a representative sample of the new correction factors for neutron generated secondary gamma rays. Experience has shown that secondary gamma ray dose variation is not as smooth as the neutrons or prompt gamma rays variation, thus it takes more coefficients to represent each curve as it will be detailed in the next section. The data for secondary gamma rays is everywhere dense in that TWEDEE data exists for all source heights and source energies.

Figure 7 shows examples of the new correction factors for prompt gamma rays. As expected, the curves exhibit a generally friendly behavior and each may be parameterized by fewer coefficients than neutrons or secondary gamma rays.

Table III. List of Horizontal Ranges in Meters for the New Data Base

1.	5	7.	400
2.	10	8.	600
3.	50	9.	800
4.	100	10.	1000
5.	200	11.	1200
6.	300	12.	1300

Table IV. List of Source Heights in Meters for the New Data Base

1.	1	8.	500
2.	10	9.	600
3.	50	10.	700
4.	100	11.	800
5.	200	12.	900
6.	300	13.	1000
7.	400	14.	1100

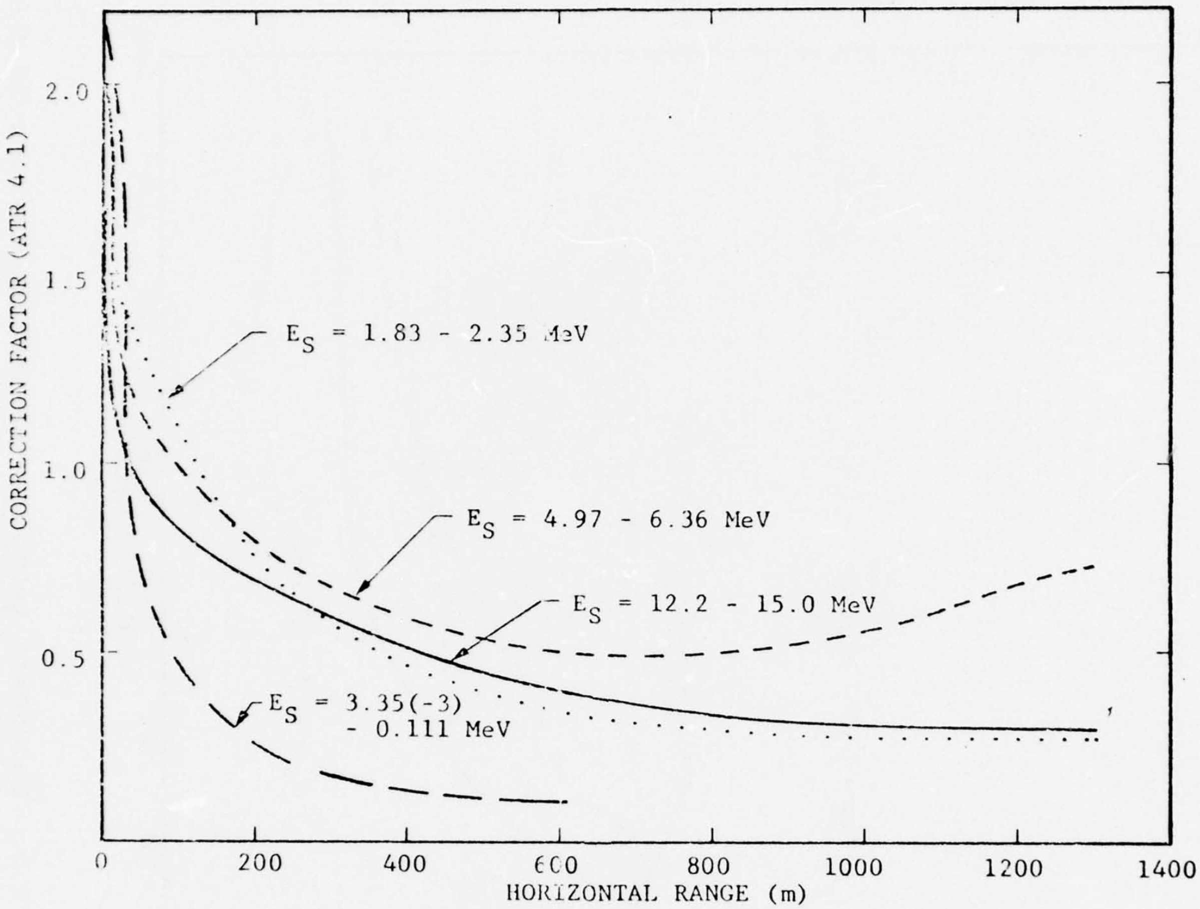

Figure 5. Neutron correction factor as a function of horizontal range for various neutron monoenergetic sources and a source height of 1 meter and a target height of 1.75 meters.

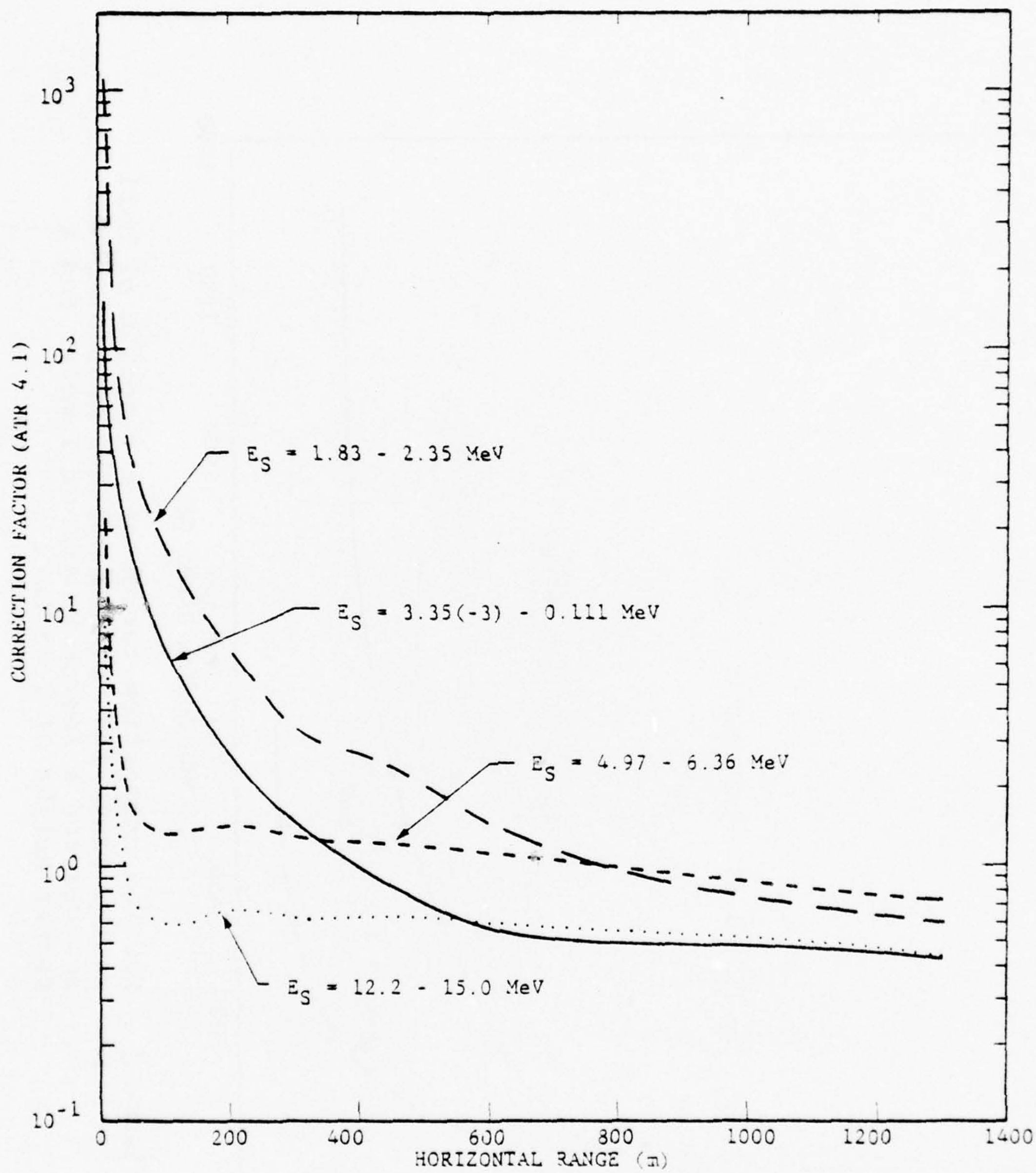

Figure 6. Secondary gamma ray correction factors as a function of horizontal range for various neutron monoenergetic sources and a source height of 1 meter and a target height of 1.75 meters.

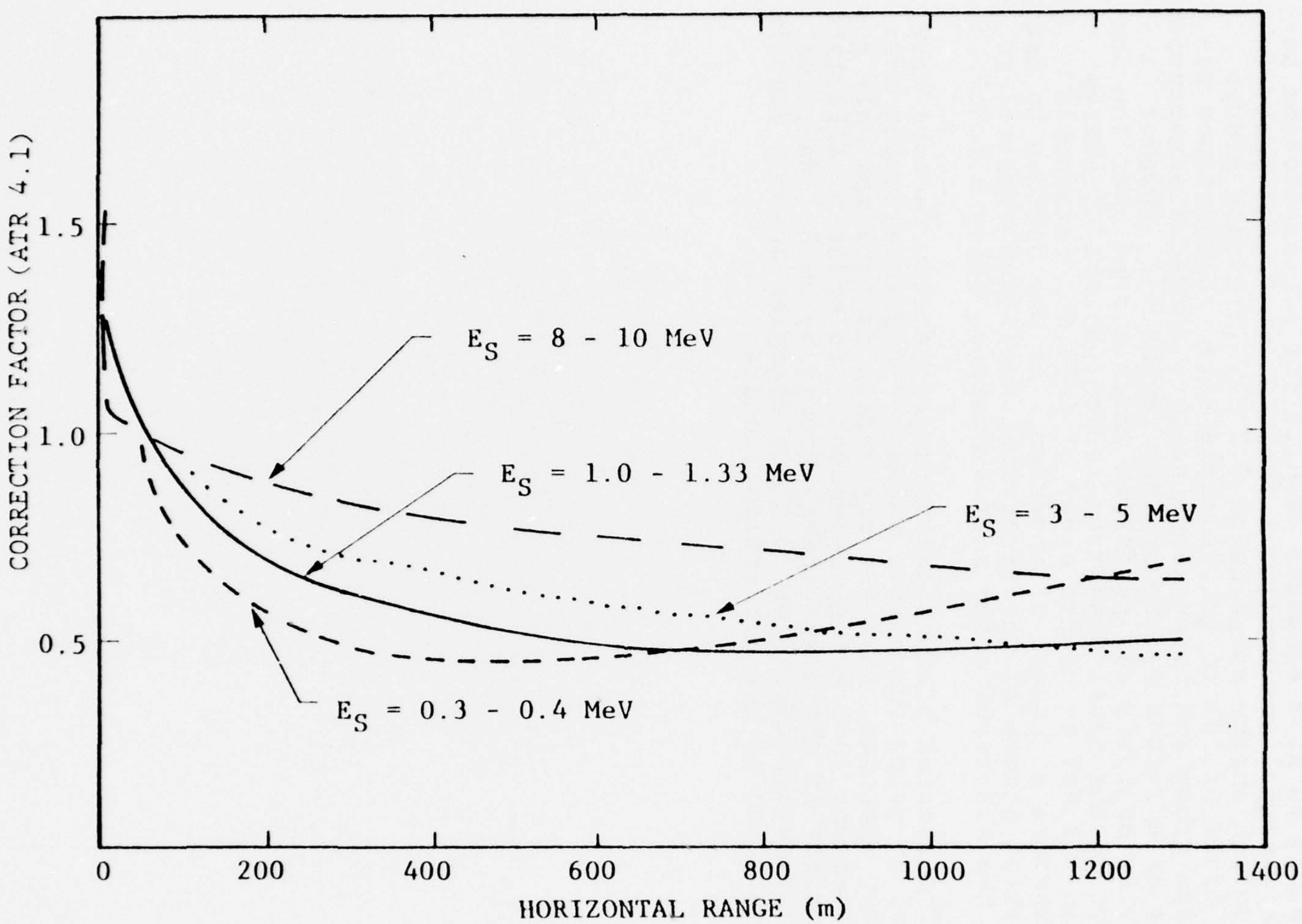

Figure 7. Prompt gamma ray correction factors as a function of horizontal range for various prompt gamma ray monoenergetic sources, a source height of 1 meter and a target height of 1.75 meters.

The TWEDEE group structure below 0.2 MeV was found to be too broad to give accurate results for source photons below this energy. As detailed in Ref. 2, it is necessary to partition the energy range below 0.2 MeV into many groups (on the order of 30) to get reliable data. Comparisons between fine group and broad group results showed discrepancies as large as a factor of two in this regime.[2] However, a sensitivity analysis was performed which showed that the contribution to the total dose from source photons of energy less than 0.2 MeV is on the order of 1.5% for reasonable source spectra at ranges of interest. It was decided to use the existing scheme of the first-last collision model[1] to correct the ATR results for source energies below 0.2 MeV.

The fission product gamma ray correction factors were generated by using the source values[1] and integrating over the source spectrum, thus the correction factors are only geometry dependent, not energy dependent. In order to alleviate the disparity of the lower energy groups below 0.2 MeV, the source values corresponding to those energies are not used in the computation of the correction factors.

5. PARAMETRIZATION OF AIR/GROUND CORRECTION FACTORS

Three subroutines (AGNEUT, AGGAMM, AGSGAM) have been written and tested that provide the parametrized air/ground correction factors for neutrons, prompt gammas and secondary gammas. These routines use coefficients generated by a piecewise least squares fitting of the appropriate data to algebraic functions of various modified polynominal forms. The parameters of the fits are heuristically selected so as to obtain the minimum error and least number of coefficients. The coefficients so generated are arranged by source energy groups for ease of use and incorporation into the ATR code. For the fission product gamma rays a set of coefficients are generated for each source height and fit as a function of horizontal range.

The basic operation of the functions is as follows. First, the source height desired is delimited between the points of the data base after which the desired horizontal range is isolated. These values are then used to locate a pointer word which contains information about the location and number of coefficients and type of function to be used in computing the air/ground ratio. The ratio is then computed for adjacent source heights and a linear interpolation between source height values is used to return the final value of the desired correction factor. When the horizontal range is less than three meters, an extrapolation is used to assign an appropriate air/ground ratio by using the results at three meters and at five meters.

The modified algebraic functions used to parametrize the original data base assume the following forms, where C_T is the ratio for neutrons and prompt gamma rays is the log of the ratio for secondary gamma rays.

Function Type 0:

$$a_4 x^4 + a_3 x^3 + a_2 x^2 + a_1 x^1 + a_0 = C_T \tag{6}$$

Function Type 1:

$$a_4 x^3 + a_3 x^2 + a_2 x + a_1/x + a_0 = C_T \tag{7}$$

Function Type 2:

$$a_4/x^4 + a_3/x^3 + a_2/x^2 + a_1/x + a_0 = C_T \tag{8}$$

Function Type 3:

$$a_4 x^3 + a_3 x^2 + a_2 x + a_1 \sqrt{x} + a_0 = C_T \qquad (9)$$

In addition, an extrapolation function is used when the horizontal range is less than three meters. If the horizontal range is larger than the span of the data base, then the value corresponding to the last horizontal range in the data base is used.

The pointer word which contains information regarding the location and number of coefficients and the type of function is composed as follows, numbering from the right with the rightmost binary bit numbered one.

Bits 1-4 - Source Height Index
Bits 5-8 - Horizontal Range Index (start)
Bits 9-12 - Horizontal Range Index (stop)
Bits 13-15 - Number of Coefficients
Bits 16-17 - Type of Function
Bits 18-28 - Starting Location of Coefficients Within Coefficient Array

These pointer words are grouped according to source energy group. Within each group there is a pointer word for each piecewise fit. For example, assume that the third through eighth points of source energy group six, source height ten were fitted to the function of the form $a_1 x + a_0 = C_T$. The pointer word containing this information would be located in index group six (for source energy group six) and appear in binary as follows:

Location of Coefs.	00	010	1000	0011	1010
28 — 18	16	13	9	5	1

For machine to machine compatibility the pointer words have been stored as integers using "DATA" statements, thereby obscuring the structure. However, a simple integer to binary conversion will reveal the format.

The coefficient array consists of all coefficients generated by the fitting process arranged in the order of source energy group, source height, horizontal range and is everywhere dense. The starting location of the coefficients within the array for a particular piecewise fit is stored in the corresponding pointer word as previously described.

This process resulted in a total of 3365 coefficients, 1073 to generate the neutron data base, 1249 to generate the prompt gamma data base and 1043 to generate the secondary gamma data base. The original data base contained approximately 9800 points. Therefore, the parametrization resulted in a reduction of approximately 6435 data points or 65 per cent.

6. ATR VERSION 4.1

The routines described in the previous section were incorporated into ATR Version 4[1] and the new version will be called 4.1. Here the results are presented for each "particle" type at several geometry configurations. There are four figures for each radiation type for a 1 KT burst, each figure containing three curves: the first curve is without air/ground correction factors (scaled infinite air results), the second curve shows the results using the correction factors present in ATR Version 4[1] and the third curve shows the results due to the use of the new energy dependent correction factors (ATR Version 4.1).

The four geometry configurations are selected in a manner that shows the effects of both the source and the target close to and away from the ground. The first figure in each sequence has both the source and the target at one meter above the ground, the second one has the source at one meter and the target at 800 meters, the third one has the source at 800 meters and the target at one meter, and finally, the fourth one has both the source and the target at 800 meters.

Figures 8 through 11 show the results for neutrons; the source used is a typical thermonuclear spectrum with a normalization of 1.9×10^{23} neutrons/KT. Figures 12 through 15 show the results for prompt gamma rays, the source used is a typical fission spectrum with normalization of 10^{23} gammas/KT. Figures 16 through 19 show the results for secondary gamma rays and Figures 20 through 23 show the results for fission product gamma rays. Note that the largest differences between ATR 4 and ATR 4.1 results occur for the gamma ray sources (prompt and delayed). The correction factors for gamma ray sources for ATR 4.1 are based on transport data while the ATR 4 corrections were based on an unverified model.

There is no visible impact to the user as far as the ATR Version 4.1 command structure is concerned, only some of the internal mechanism is different. The Appendix contains a composite sample problem that illustrates the use of ATR Version 4.1.

The ATR 4.1 version has the follow features which are not present in ATR 4:

- Air ground correction factors which explicitly treat variations in the neutron and gamma ray source energy spectra

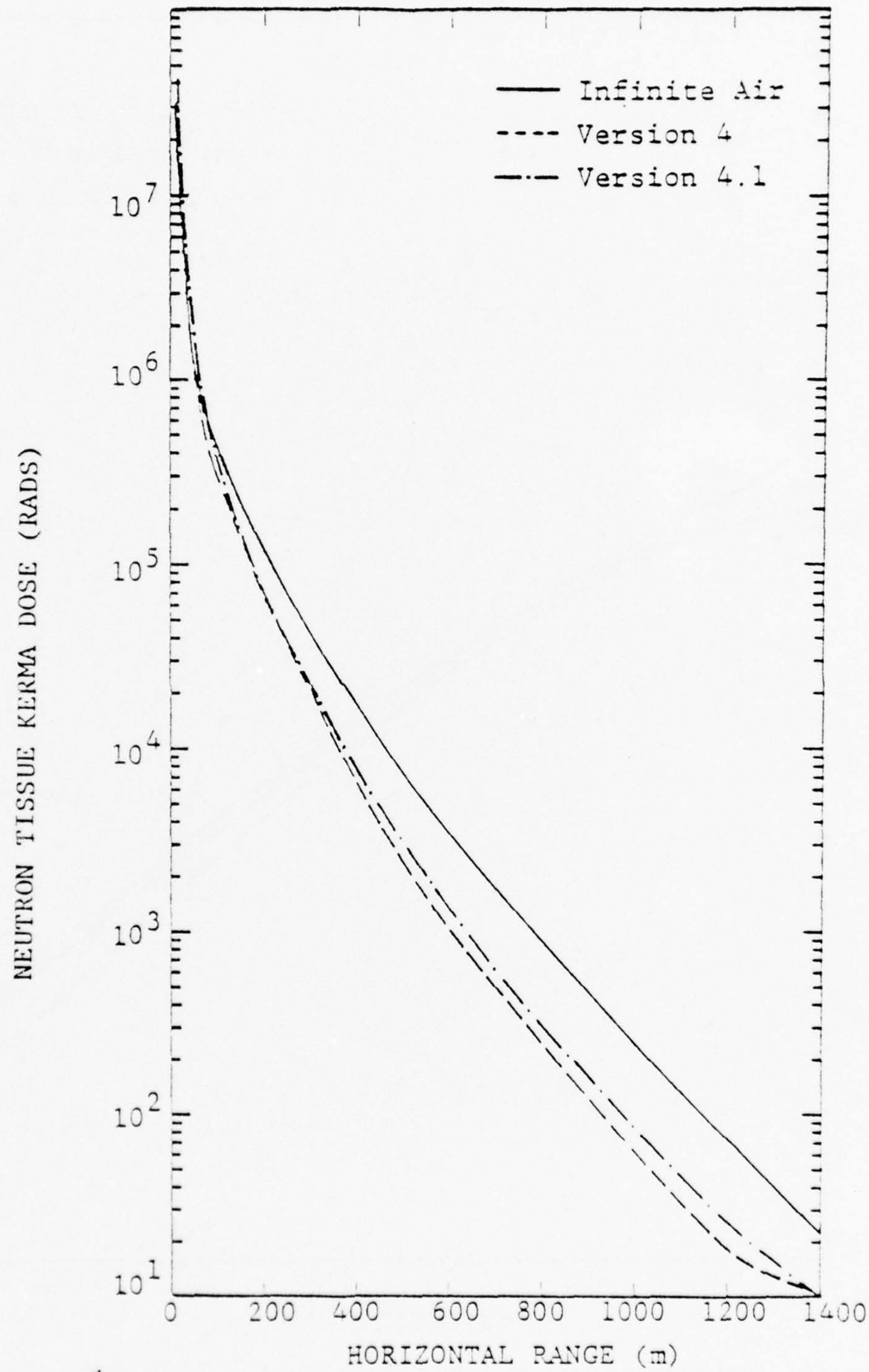

Figure 8. Neutron tissue kerma dose for a 1 KT yield, source height of 1 meter, target height of 1 meter and various air/ground correction factors for a typical thermonuclear source.

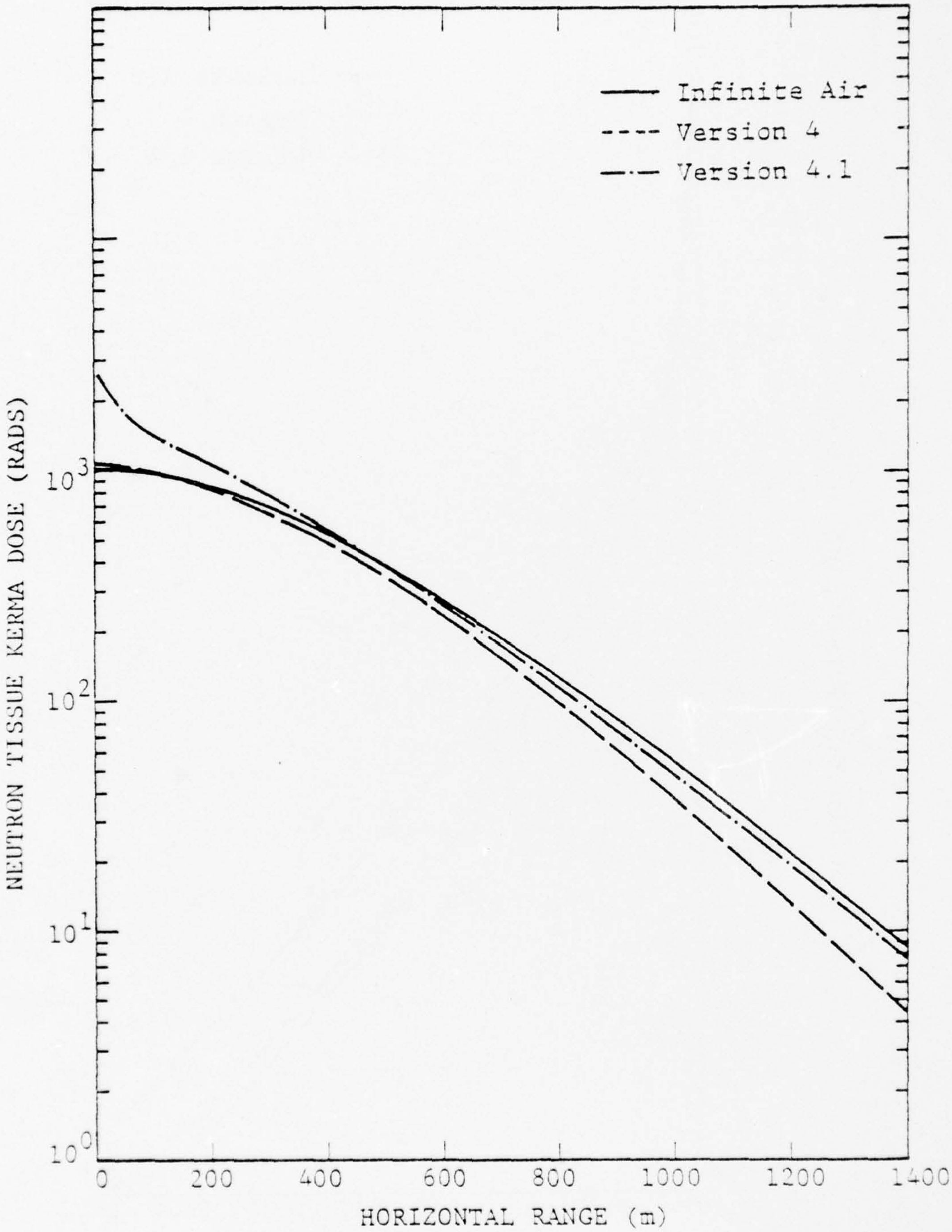

Figure 9. Neutron tissue kerma dose for a 1 KT yield, source height of 1 meter, target height of 800 meters and various air/ground correction factors for a typical thermonuclear source.

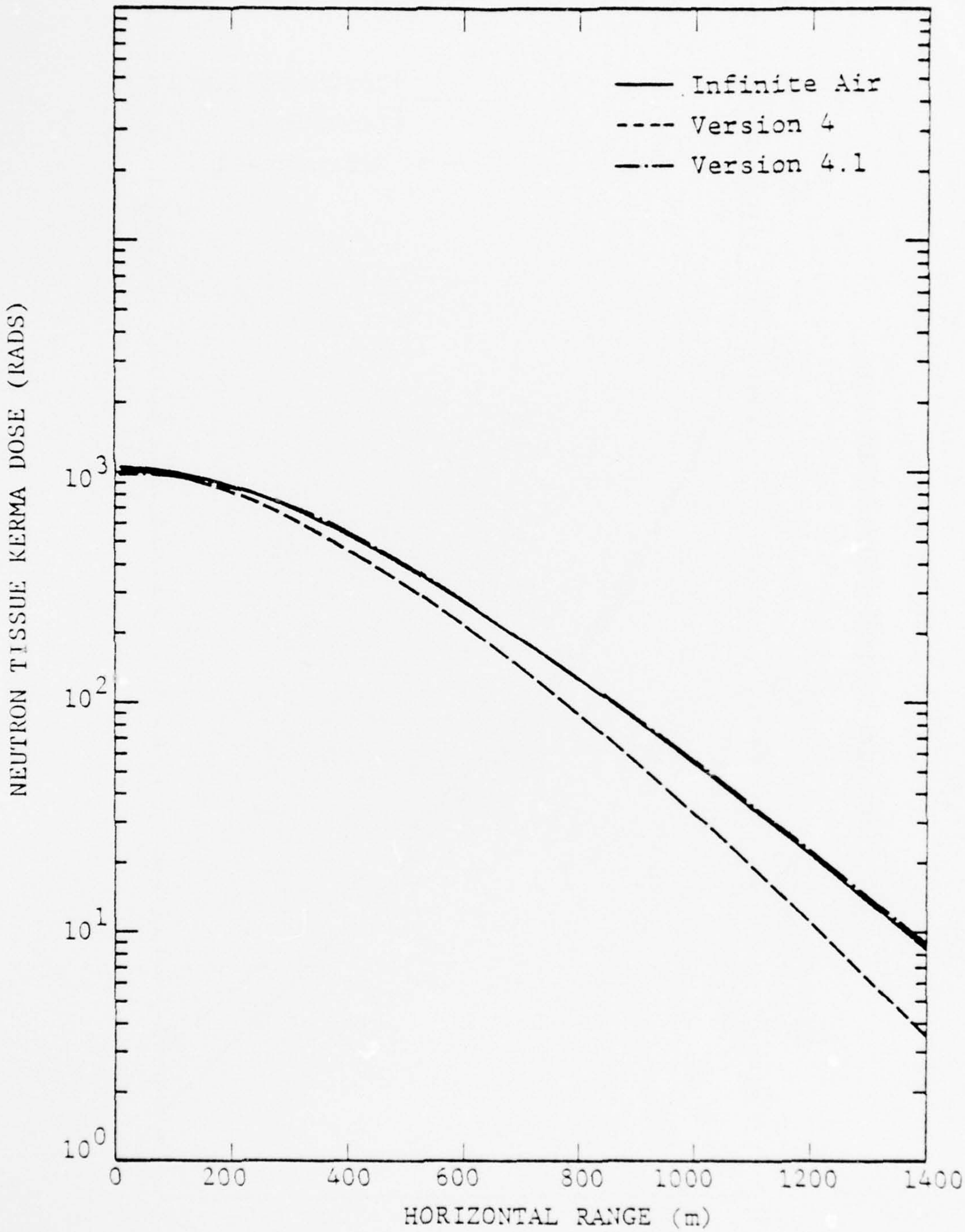

Figure 10. Neutron tissue kerma dose for a 1 KT yield, source height of 800 meters, target height of 1 meter and various air/ground correction factors for a typical thermonuclear source.

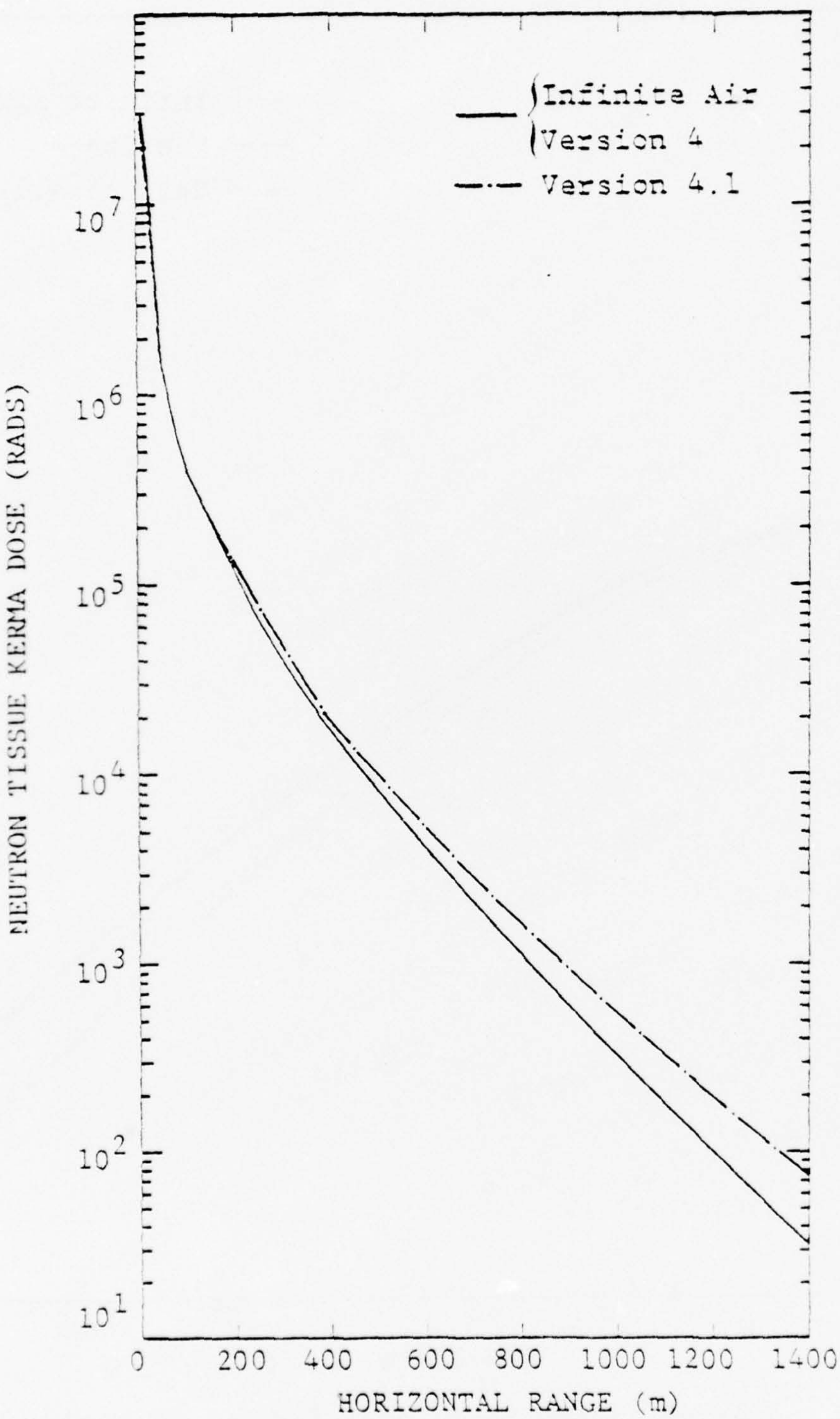

Figure 11. Neutron tissue kerma dose for a 1 KT yield, source height of 800 meters, target height of 800 meters and various air/ground correction factors for a typical thermonuclear source.

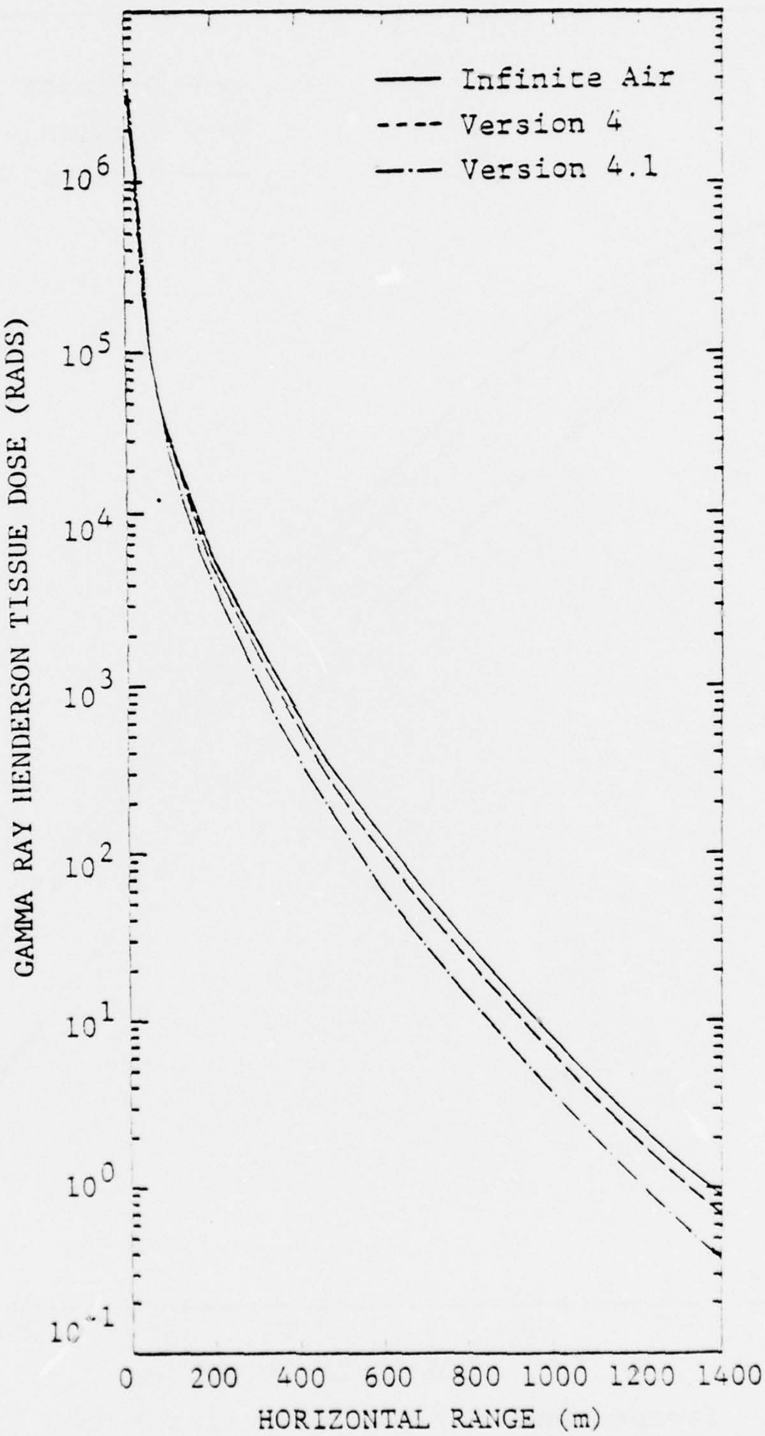

Figure 12. Prompt gamma ray Henderson tissue dose for a 1 KT yield, source height of 1 meter, target height of 1 meter and various air/ground correction factors for a typical fission source.

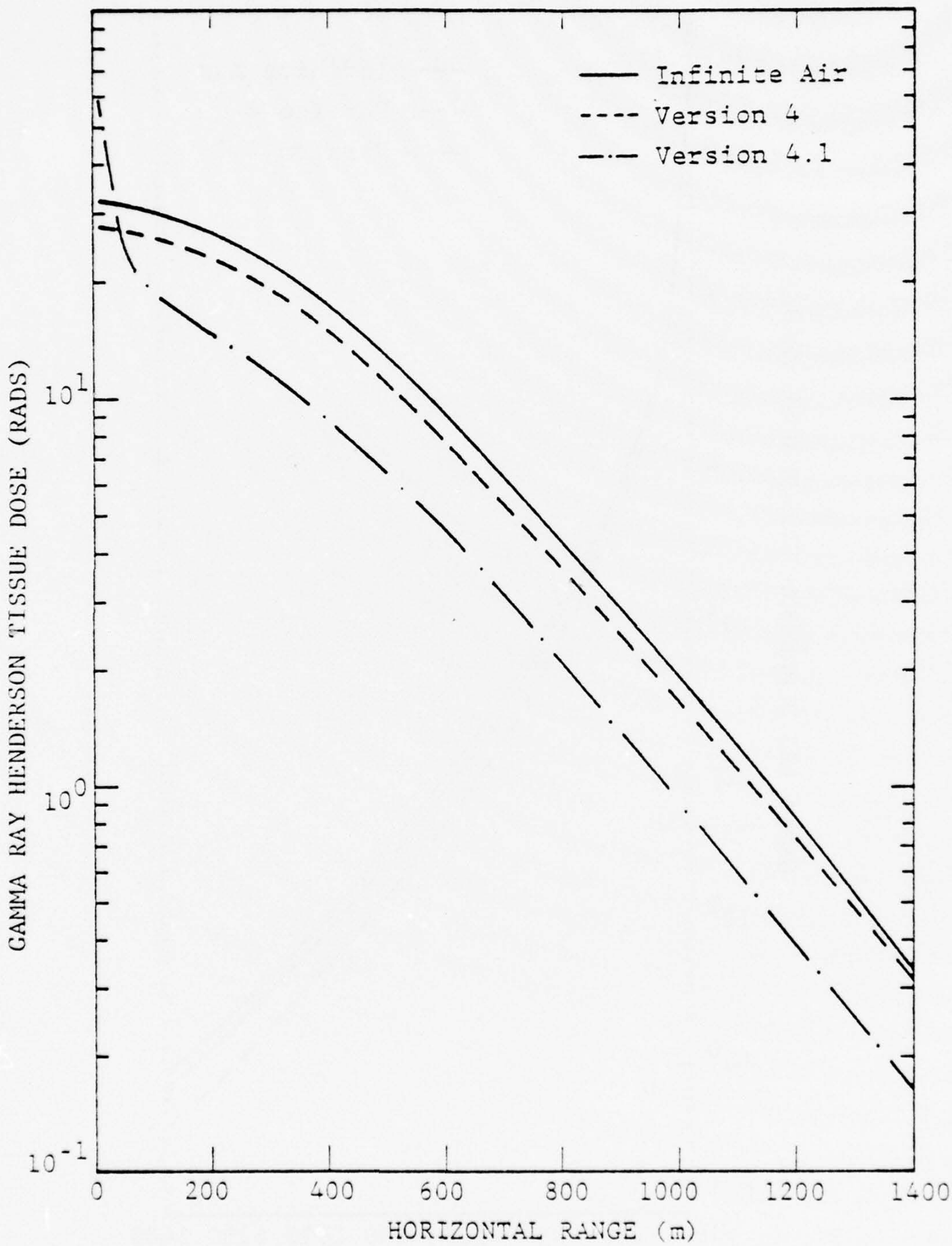

Figure 13. Prompt gamma ray Henderson tissue dose for a 1 KT yield, source height of 1 meter, target height of 800 meters and various air/ground correction factors for a typical fission source.

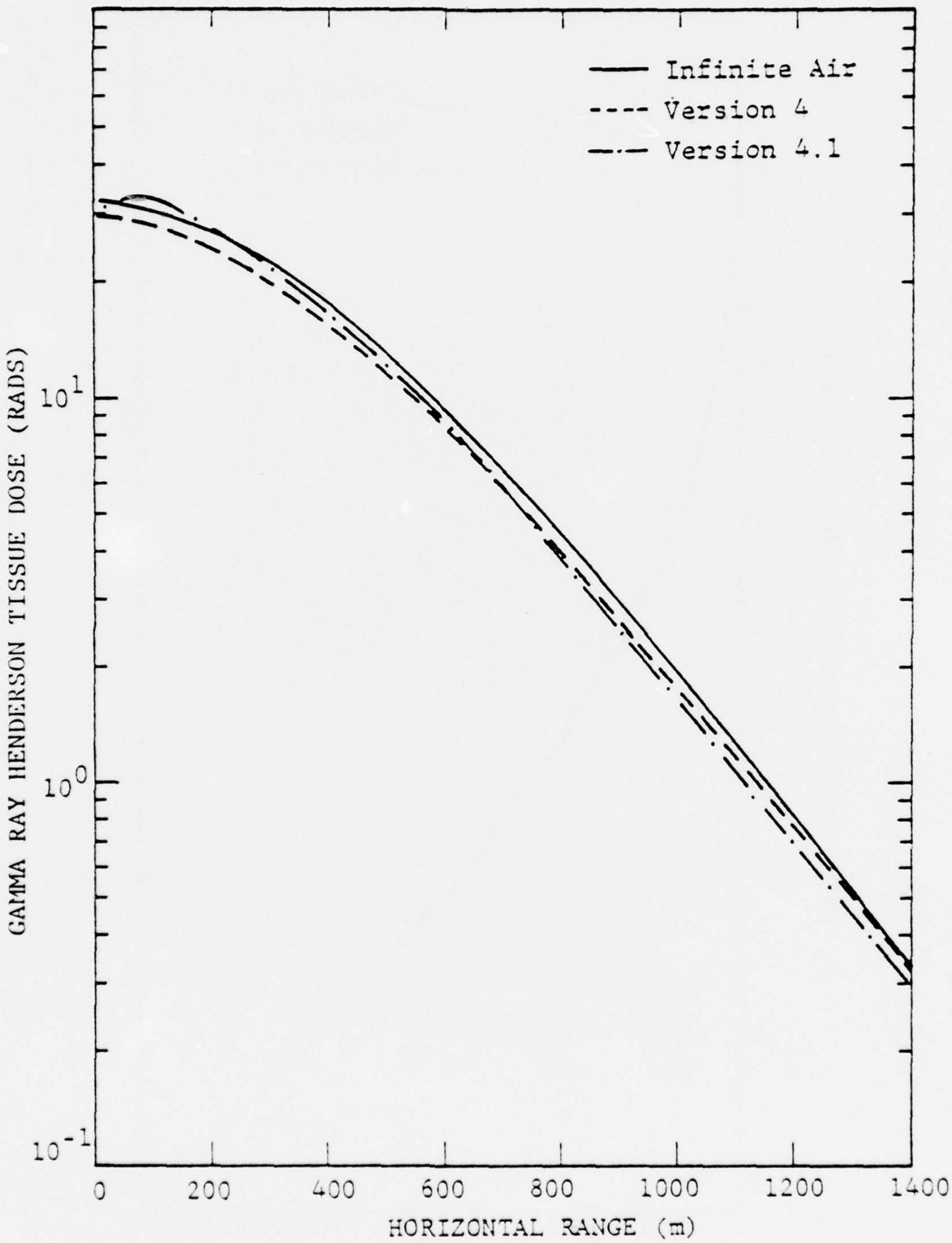

Figure 14. Prompt gamma ray Henderson tissue dose for a 1 KT yield, source height of 800 meters, target height of 1 meter and various air/ground correction factors for a typical fission source.

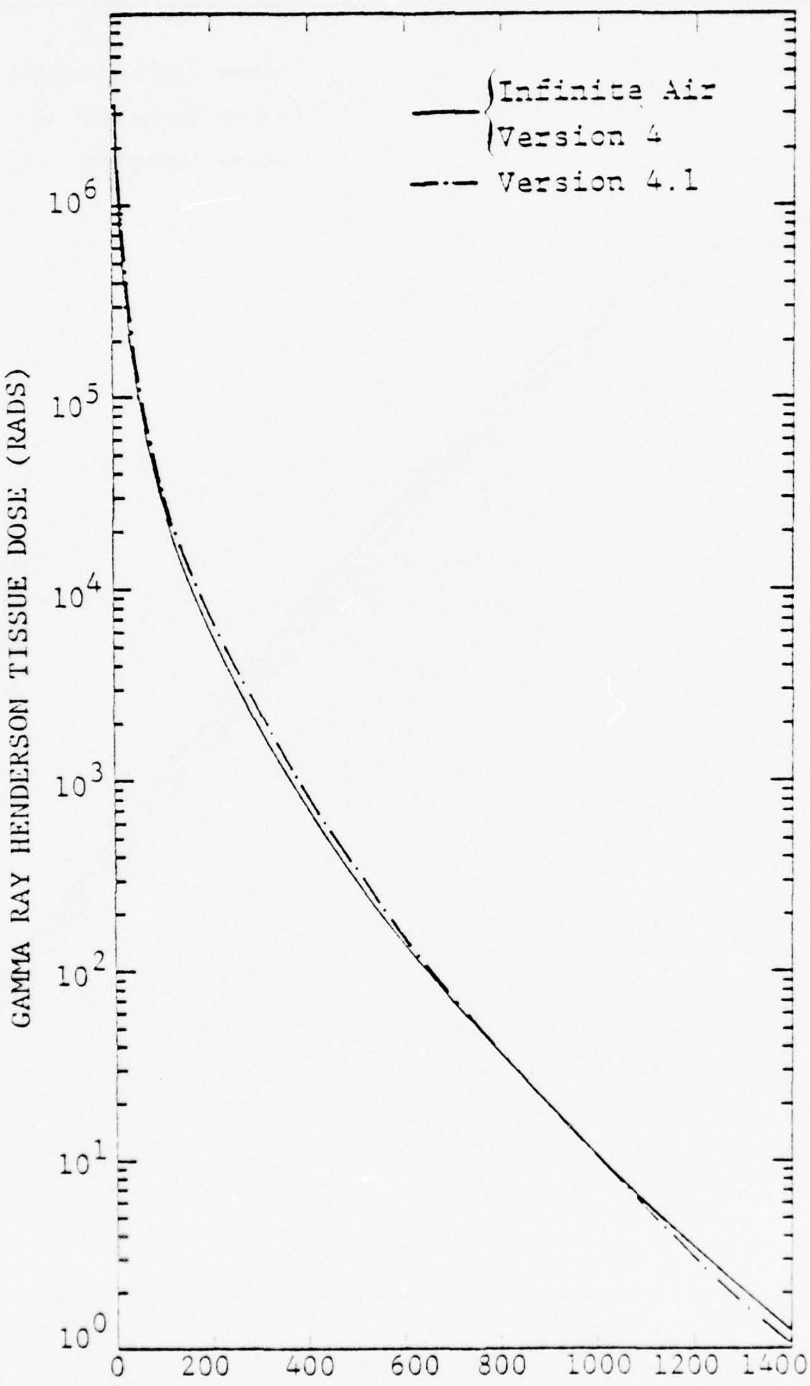

Figure 15. Prompt gamma ray Henderson tissue dose for a 1 KT yield, source height of 800 meters, target height of 800 meters and various air/ground correction factors for a typical fission source.

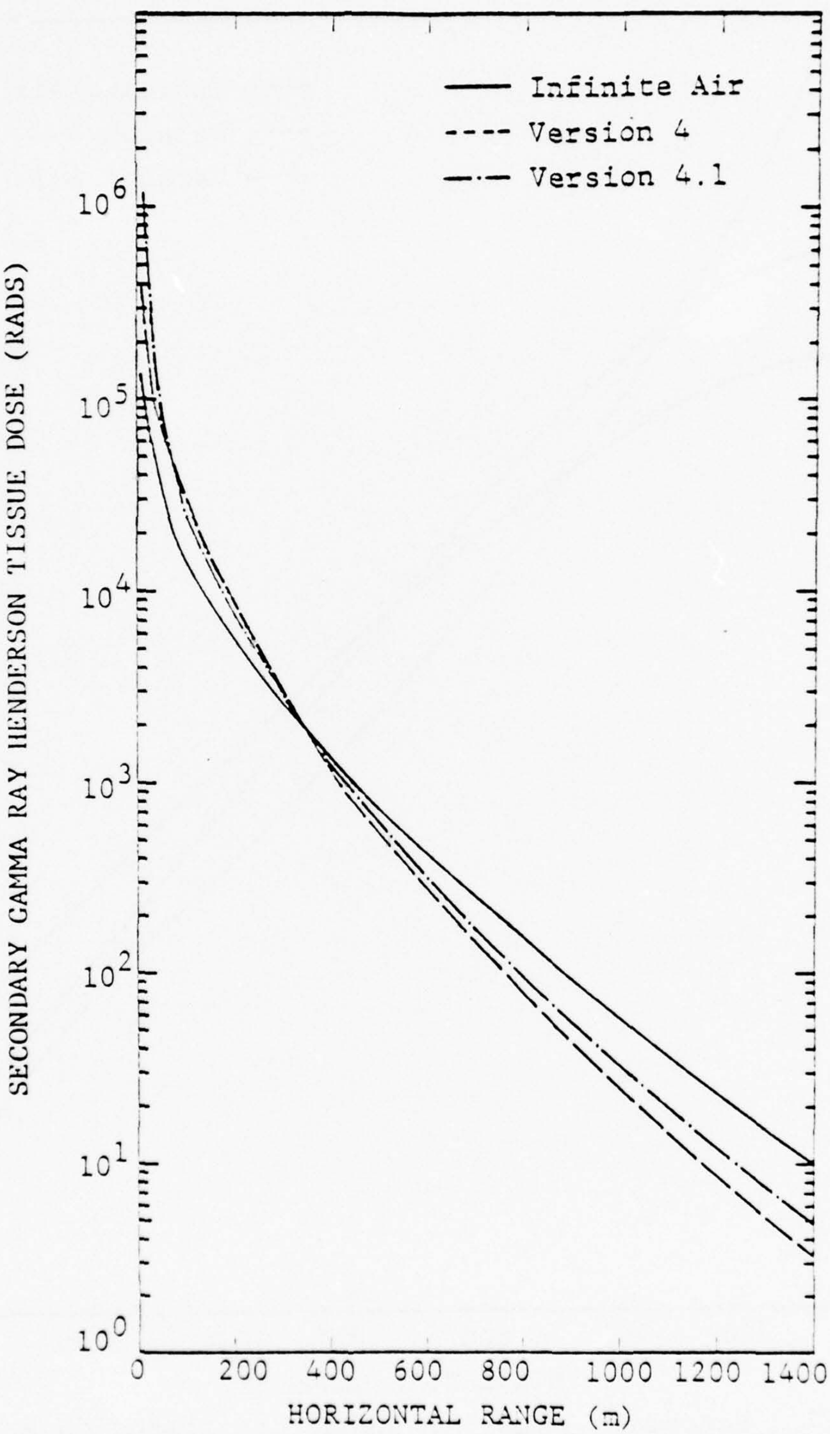

Figure 16. Secondary gamma ray Henderson tissue dose for a 1 KT yield, source height of 1 meter, target height of 1 meter and various air/ground correction factors for a typical thermonuclear neutron source.

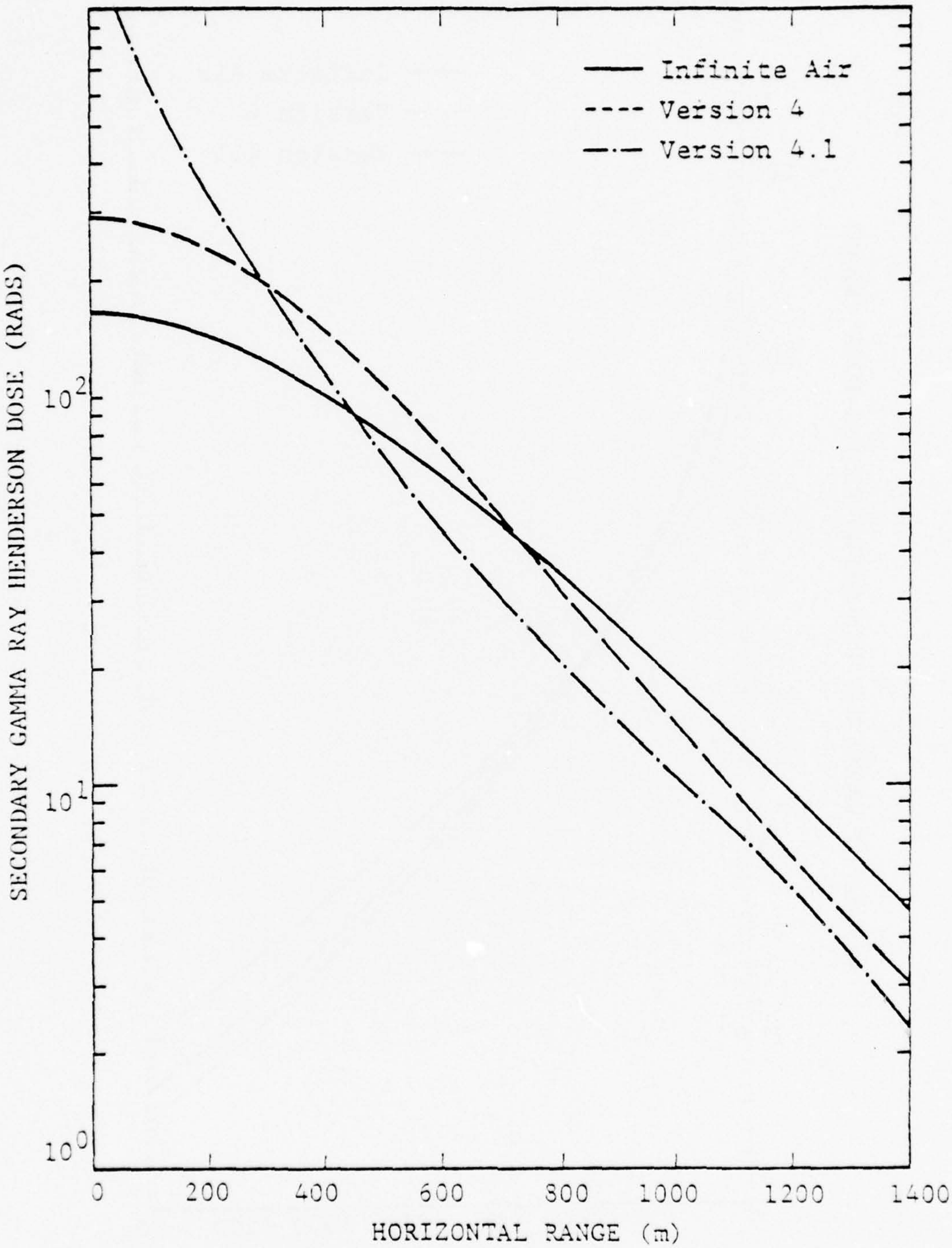

Figure 17. Secondary gamma ray Henderson tissue dose for a 1 KT yield, source height of 1 meter, target height of 800 meters and various air/ground correction factors for a typical thermonuclear neutron source.

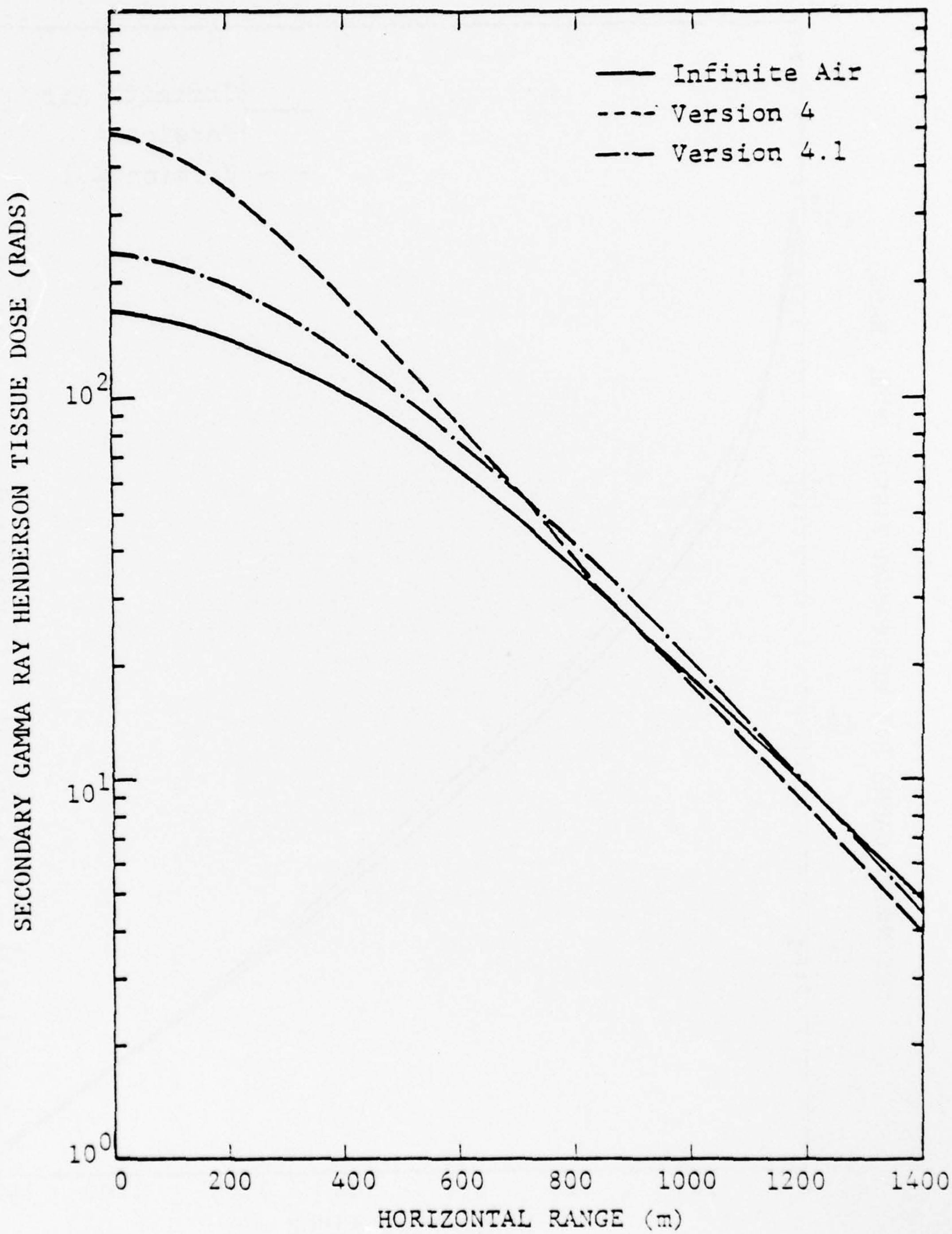

Figure 18. Secondary gamma ray Henderson tissue dose for a 1 KT yield, source height of 800 meters, target height of 1 meter and various air/ground correction factors for a typical thermonuclear neutron source.

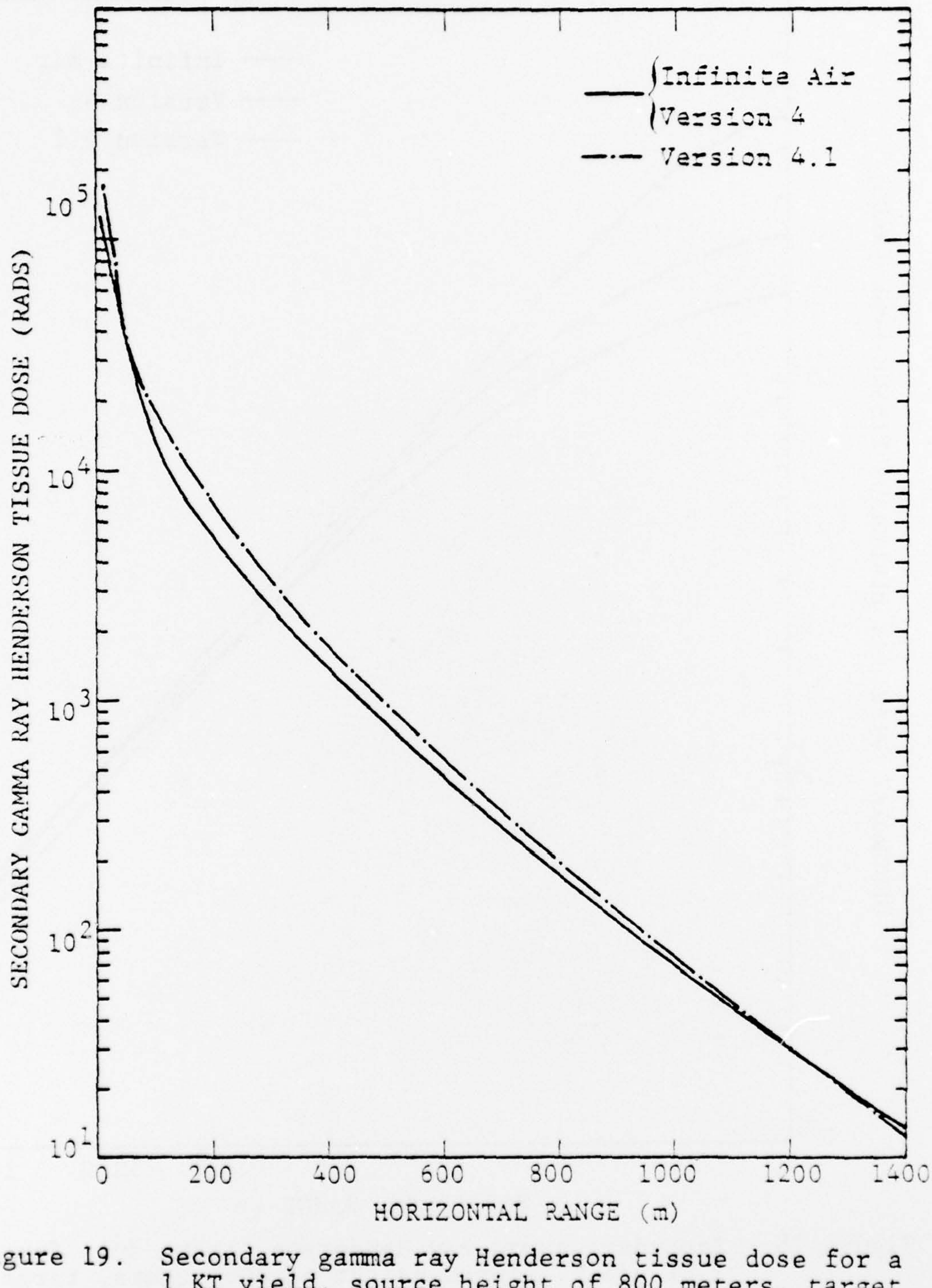

Figure 19. Secondary gamma ray Henderson tissue dose for a 1 KT yield, source height of 800 meters, target height of 800 meters and various air/ground correction factors for a typical thermonuclear neutron source.

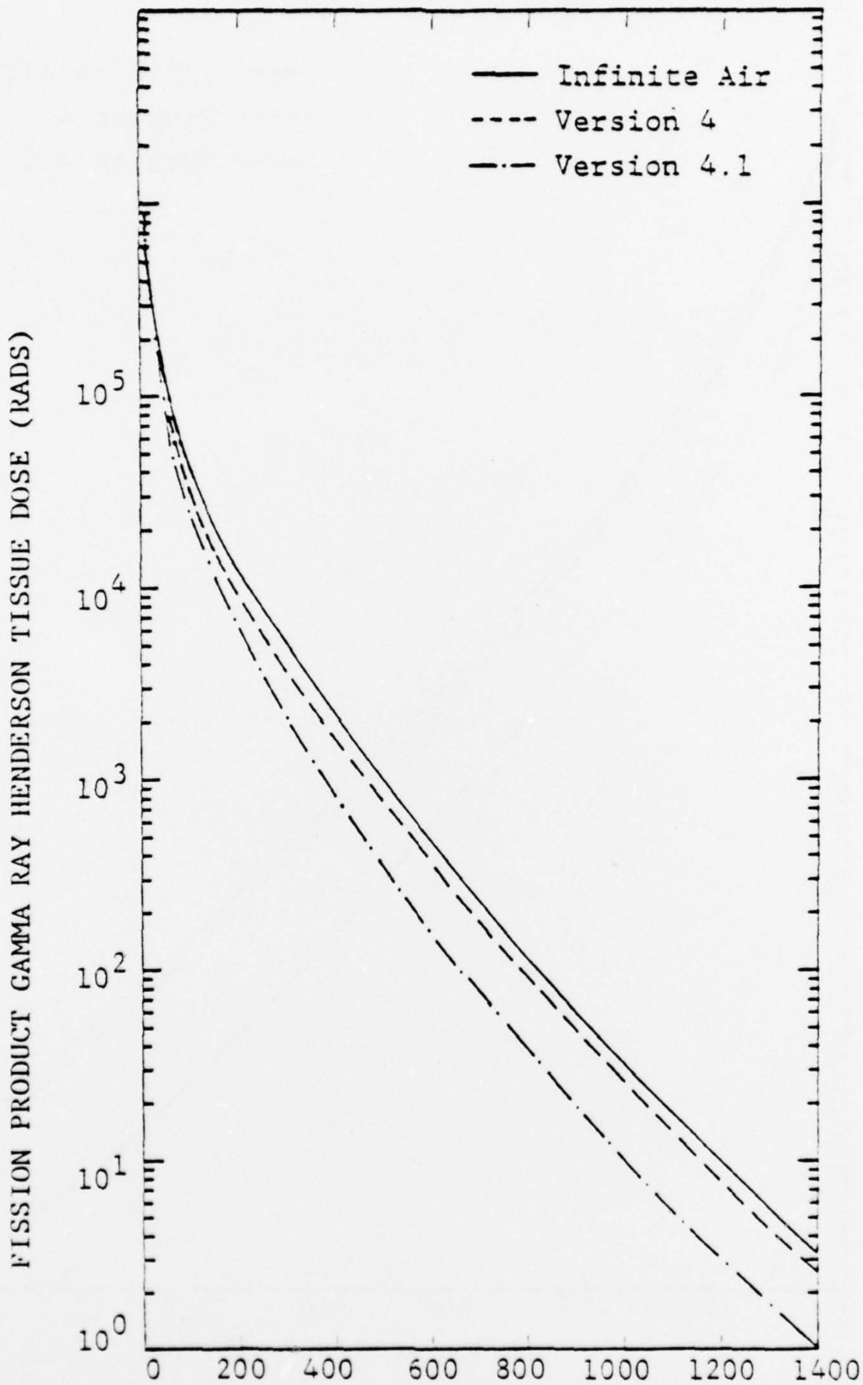

Figure 20. Fission product gamma ray Henderson tissue dose for a 1 KT yield, source height of 1 meter, target height of 1 meter and various air/ground correction factors for a delayed gamma ray source.

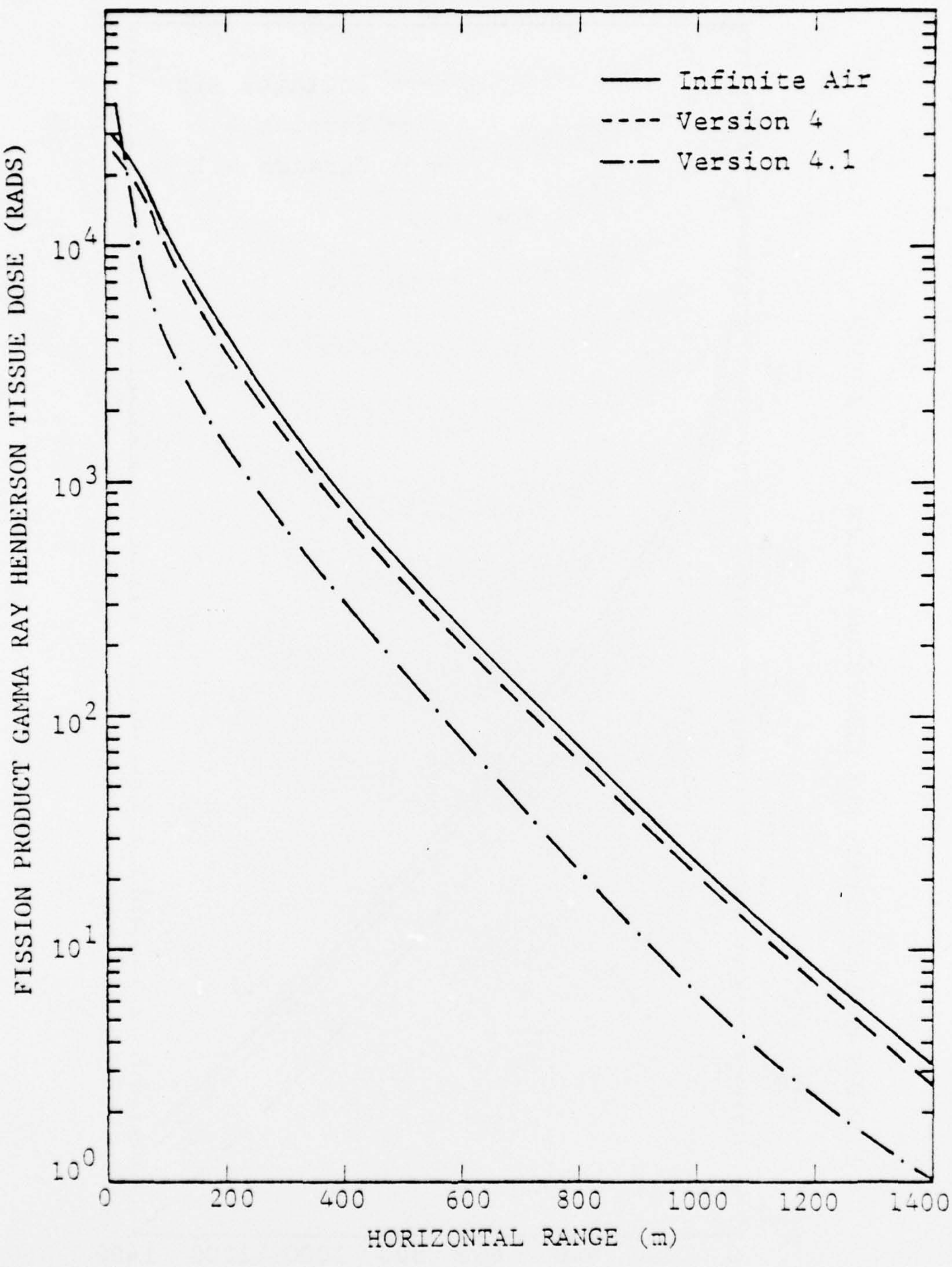

Figure 21. Fission product gamma ray Henderson tissue dose for a 1 KT yield, source height of 1 meter, target height of 800 meters and various air/ground correction factors for a delayed gamma ray source.

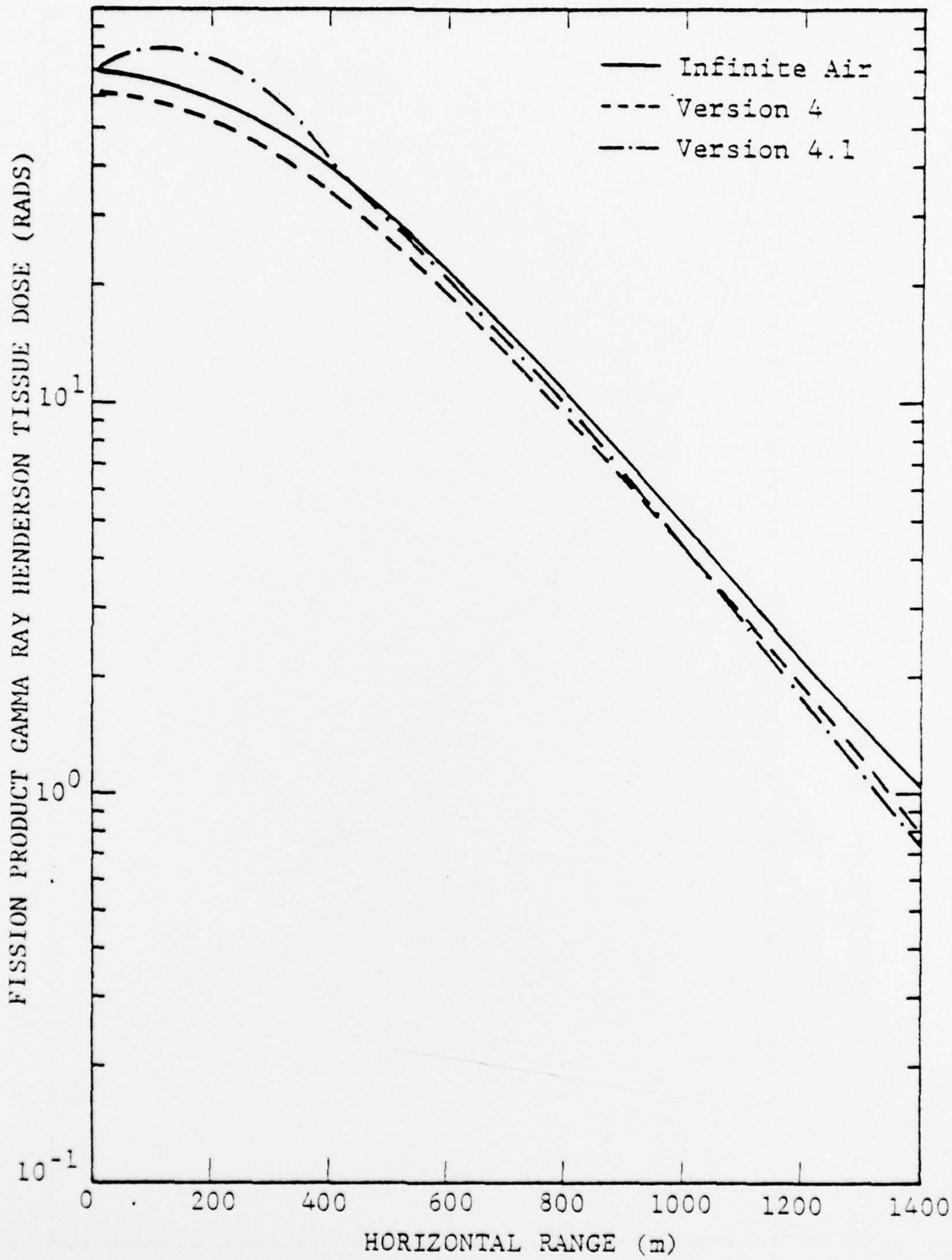

Figure 22. Fission product gamma ray Henderson tissue dose for a 1 KT yield, source height of 800 meters, target height of 1 meter and various air/ground correction factors for a dealyed gamma ray source.

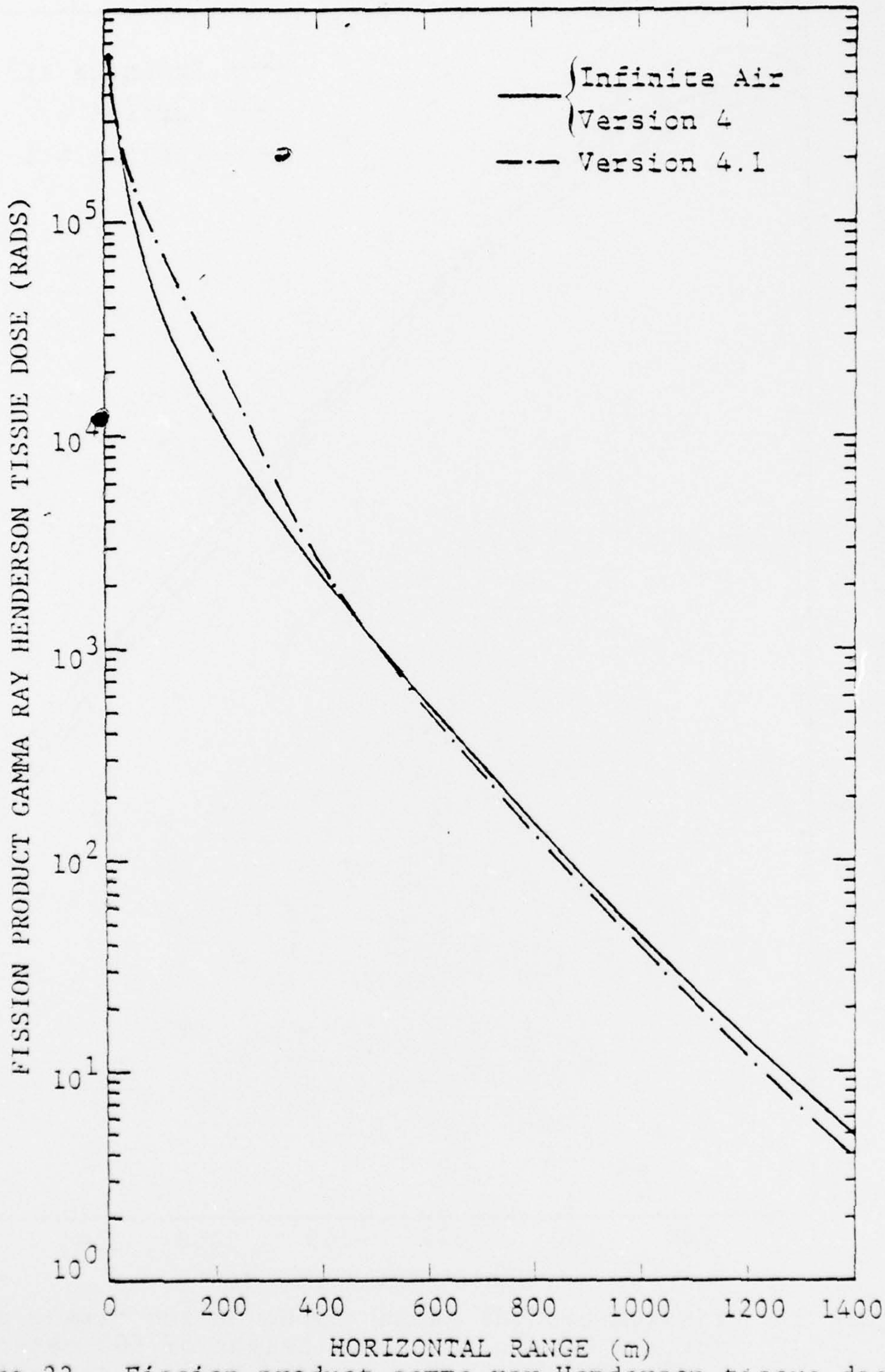

Figure 23. Fission product gamma ray Henderson tissue dose for a 1 KT yield, source height of 800 meters, target height of 800 meters and various air/ground correction factors for a dealyed gamma ray source.

- Air ground correction factors generated from transport calculations in which the ground composition is more realistic for tactical scenarios than the NTS composition
- Air ground correction factors for gamma ray sources which are based on detailed transport calculations rather than a mathematical model.

These additional features will permit a more accurate analysis of the radiation environments in tactical nuclear weapon scenarios.

It should be noted that there is no set of correction factors which could be incorporated into ATR which would be appropriate for all possible analysis of weapon effects in air over ground configurations. The number of combinations of source height, source energy, target height, target energy, target angular distribution, and ground composition is too large to even hope to generate a data base or to incorporate such a data base into ATR. There are, however, three remaining portions of the air over ground radiation environments which could stand reasonable improvement with models based on calculations. These are:

- Variation of the dose as a function of hydrogen content in the soil
- Variation of the dose as a function of target height
- Estimation of the "upward" and "downward" component with respect to the ground of the radiation environment.

7. REFERENCES

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3. L. Huszar, L. F. Nesseler and W. A. Woolson, "User's Guide to Version 2 of ATR (Air Transport of Radiation)," SAI-73-534-LJ, DNA3144Z, April 1973.

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5. R. L. French, "A First-Last Collision Model of Air-Ground Interface Effects on Fast Neutron Distribution," Nuclear Science and Engineering <u>19</u>, 151 (1964).

6. J. V. Pace, III, D. E. Bartine and F. R. Mynatt, "Neutron and Secondary-Gamma-Ray Transport Calculations for 14-MeV and Fission Neutron Sources in Air-Over-Ground and Air-Over-Seawater Geometries," ORNL-TM-4841, August 1975.

7. M. L. Gritzner, E. A. Straker, T. E. Albert and H. T. Smith, "Radiation Environments from Tactical Nuclear Weapons," Science Applications, Inc., SAI-76-534-HU, May 1975.

APPENDIX A

SAMPLE PROBLEM

This sample problem is a composite of four different radiation types: neutrons, prompt, secondary and fission product gamma rays. The source selection for neutrons and secondary gamma rays is a typical thermonuclear spectrum with a normalization of 1.9×10^{23} neutrons, for prompt gamma rays it is a typical fission spectrum with a normalization of 10^{23} gamma rays. The fission product yield is specified as 1 KT.

The geometry configuration is given as the source and target one meter off the ground and the horizontal range varies from 10 meters to 1400 meters.

The output request is simply all of the dose responses for all of the radiation components.

The output contains the details of the source configurations followed by the output of the dose response for all of the requested components.

A.1 SAMPLE PROBLEM INPUT COMMANDS

```
*TITLE SAMPLE PROBLEM FOR ATR VERSION 4.1
*N-SOURCE(2)
*N-NORM 1.9+23
*G-SOURCE(1)
*G-NORM 1+23
*FP-Y 1
*HS 1
*HT 1
*RH 10 50 100 200(200)1400
*DOSE/N/
*DOSE/G/
*DOSE/NG/
*DOSE/FP/
*EXC
*FIN
```

A.2 SAMPLE PROBLEM OUTPUT

```
VERSION 4.1 OF ATRNXG - BRL AIR/GROUND

ATR PROBLEM NUMBER       1              SAMPLE PROBLEM FOR ATR VERSION 4.1

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

NEUTRON  SOURCE       INTERNAL  THERMONUCLEAR
NORMALIZATION=1.900E+23 NEUTRON /KT, YIELD=1.000E+00 KT
 TOTAL OUTPUT=1.900E+23 NEUTRON

                         SOURCE SPECTRUM
 ENERGY(MEV )         N          N/MEV    ENERGY(MEV )         N          N/MEV
1.07E-05-2.90E-05 0.00E-01 0.00E-01 2.35E+00-2.46E+00 9.50E+20 8.64E+21
2.90E-05-1.01E-04 3.80E+20 5.28E+24 2.46E+00-3.01E+00 3.61E+21 6.56E+21
1.01E-04-5.83E-04 4.56E+21 9.46E+24 3.01E+00-4.07E+00 4.94E+21 4.66E+21
5.83E-04-3.35E-03 2.32E+22 8.38E+24 4.07E+00-4.97E+00 3.23E+21 3.59E+21
3.35E-03-1.11E-01 6.93E+22 6.44E+23 4.97E+00-6.36E+00 3.42E+21 2.46E+21
1.11E-01-5.50E-01 1.94E+22 4.41E+22 6.36E+00-8.19E+00 2.79E+21 1.53E+21
5.50E-01-1.11E+00 1.61E+22 2.88E+22 8.19E+00-1.00E+01 2.68E+21 1.48E+21
1.11E+00-1.83E+00 1.18E+22 1.64E+22 1.00E+01-1.22E+01 4.86E+21 2.21E+21
1.83E+00-2.35E+00 5.32E+21 1.02E+22 1.22E+01-1.50E+01 1.34E+22 4.79E+21

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ATR PROBLEM NUMBER       1              SAMPLE PROBLEM FOR ATR VERSION 4.1

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

GAMMA    SOURCE       INTERNAL  FISSION
NORMALIZATION=1.000E+23 GAMMA   /KT, YIELD=1.000E+00 KT
 TOTAL OUTPUT=1.000E+23 GAMMA

                         SOURCE SPECTRUM
 ENERGY(MEV )         G          G/MEV    ENERGY(MEV )         G          G/MEV
2.00E-02-5.00E-02 3.08E+21 1.03E+23 1.33E+00-1.66E+00 6.18E+21 1.87E+22
5.00E-02-1.00E-01 1.35E+21 2.71E+22 1.66E+00-2.00E+00 3.93E+21 1.16E+22
1.00E-01-2.00E-01 8.16E+21 8.16E+22 2.00E+00-2.50E+00 3.76E+21 7.51E+21
2.00E-01-3.00E-01 6.87E+21 6.87E+22 2.50E+00-3.00E+00 2.23E+21 4.47E+21
3.00E-01-4.00E-01 8.68E+21 8.68E+22 3.00E+00-4.00E+00 2.12E+21 2.12E+21
4.00E-01-6.00E-01 1.77E+22 8.84E+22 4.00E+00-5.00E+00 7.48E+20 7.48E+20
6.00E-01-8.00E-01 1.40E+22 7.01E+22 5.00E+00-6.50E+00 3.23E+20 2.15E+20
8.00E-01-1.00E+00 1.00E+22 5.02E+22 6.50E+00-8.00E+00 6.79E+19 4.53E+19
1.00E+00-1.33E+00 1.07E+22 3.25E+22 8.00E+00-1.00E+01 1.58E+19 7.90E+18

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ATR PROBLEM NUMBER       1              SAMPLE PROBLEM FOR ATR VERSION 4.1

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

FISSION PRODUCT YIELD=1.00E+00KT,  FISSION FRACTION= 1.00E+00

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ATR PROBLEM NUMBER       1              SAMPLE PROBLEM FOR ATR VERSION 4.1

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
 GROUND LEVEL        0.000KM,   0.000GM/CM**2,  0.000KFT,   0.000MILES
 HORIZ. RANGE RH=   0.010KM,   1.225GM/CM**2,  0.033KFT,   0.006MILES
*SLANT RANGE  RS=   0.010KM,   1.225GM/CM**2,  0.033KFT,   0.006MILES
```

A.2 (continued)

```
TARGET ALT.  HT=  0.001KM,    0.122GM/CM**2,   0.003KFT,   0.001MILES
SOURCE ALT.  HS=  0.001KM,    0.122GM/CM**2,   0.003KFT,   0.001MILES
*SLANT ANGLE  AN=   0.000DEGREES (COS= 1.00000)
        *CALCULATED FROM OTHER COORDINATES
```

* *

```
NEUTRON             DOSE  VS.  HORIZ. RANGE      (RADS          )
                    DOSE 1=  HENDERSON TISSUE
                    DOSE 2=  SNYDER-NEUFELD
                    DOSE 3=  TISSUE
                    DOSE 4=  MID-PHANTOM
                    DOSE 5=  CONCRETE
                    DOSE 6=  AIR
                    DOSE 7=  NON-IONIZING SI.
                    DOSE 8=  IONIZING SILICON
```

HORIZ. RANGE	DOSE 1	DOSE 2	DOSE 3	DOSE 4	DOSE 5	DOSE 6	DOSE 7	DOSE 8
1.000E+01 M	3.82E+07	6.39E+07	4.29E+07	1.87E+07	6.29E+06	8.36E+06	5.00E+05	2.05E+06
5.000E+01 M	1.33E+06	2.42E+06	1.49E+06	6.64E+05	2.14E+05	2.86E+05	1.73E+04	6.60E+04
1.000E+02 M	3.25E+05	6.15E+05	3.63E+05	1.58E+05	5.04E+04	6.83E+04	4.29E+03	1.42E+04
2.000E+02 M	6.07E+04	1.12E+05	6.69E+04	2.80E+04	9.10E+03	1.24E+04	8.18E+02	2.40E+03
4.000E+02 M	6.85E+03	1.29E+04	7.59E+03	3.01E+03	9.95E+02	1.34E+03	9.31E+01	2.34E+02
6.000E+02 M	1.20E+03	2.26E+03	1.33E+03	5.05E+02	1.70E+02	2.22E+02	1.63E+01	3.67E+01
8.000E+02 M	2.73E+02	5.23E+02	3.03E+02	1.12E+02	3.81E+01	4.91E+01	3.73E+00	7.40E+00
1.000E+03 M	7.43E+01	1.44E+02	8.25E+01	2.98E+01	1.02E+01	1.30E+01	1.02E+00	1.80E+00
1.200E+03 M	2.31E+01	4.51E+01	2.56E+01	9.11E+00	3.14E+00	3.98E+00	3.15E-01	5.14E-01
1.400E+03 M	7.33E+00	1.45E+01	8.16E+00	2.90E+00	9.94E-01	1.26E+00	1.00E-01	1.58E-01

* *

```
GAMMA               DOSE  VS.  HORIZ. RANGE      (RADS          )
                    DOSE 1=  HENDERSON TISSUE
                    DOSE 2=  CONCRETE
                    DOSE 3=  AIR
                    DOSE 4=   SILICON
```

HORIZ. RANGE	DOSE 1	DOSE 2	DOSE 3	DOSE 4
1.000E+01 M	3.42E+06	3.49E+06	3.15E+06	3.39E+06
5.000E+01 M	1.09E+05	1.27E+05	9.96E+04	1.19E+05
1.000E+02 M	2.22E+04	2.87E+04	2.00E+04	2.61E+04
2.000E+02 M	3.65E+03	5.32E+03	3.23E+03	4.70E+03
4.000E+02 M	3.40E+02	5.14E+02	2.99E+02	4.50E+02
6.000E+02 M	5.88E+01	8.58E+01	5.17E+01	7.59E+01
8.000E+02 M	1.32E+01	1.83E+01	1.17E+01	1.65E+01
1.000E+03 M	3.53E+00	4.67E+00	3.12E+00	4.25E+00
1.200E+03 M	1.06E+00	1.35E+00	9.42E-01	1.25E+00
1.400E+03 M	3.55E-01	4.37E-01	3.15E-01	4.07E-01

* *

```
NEUTRON GAMMA       DOSE  VS.  HORIZ. RANGE      (RADS          )
                    DOSE 1=  HENDERSON TISSUE
                    DOSE 2=  CONCRETE
                    DOSE 3=  AIR
                    DOSE 4=   SILICON
```

HORIZ. RANGE	DOSE 1	DOSE 2	DOSE 3	DOSE 4
1.000E+01 M	1.16E+06	1.18E+06	1.06E+06	1.19E+06
5.000E+01 M	8.17E+04	8.43E+04	7.43E+04	8.51E+04

A.2 (continued)

```
 1.000E+02 M        2.86E+04 2.96E+04 2.59E+04 2.98E+04
 2.000E+02 M        7.91E+03 8.36E+03 7.16E+03 8.36E+03
 4.000E+02 M        1.29E+03 1.40E+03 1.17E+03 1.39E+03
 6.000E+02 M        2.98E+02 3.29E+02 2.68E+02 3.23E+02
 8.000E+02 M        9.30E+01 1.04E+02 8.36E+01 1.01E+02
 1.000E+03 M        3.17E+01 3.57E+01 2.85E+01 3.47E+01
 1.200E+03 M        1.19E+01 1.34E+01 1.07E+01 1.30E+01
 1.400E+03 M        4.84E+00 5.46E+00 4.34E+00 5.31E+00

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

   FISSION PRODUCT  DOSE  VS.  HORIZ. RANGE      (RADS        )
                    DOSE 1=  HENDERSON TISSUE
                    DOSE 2=  CONCRETE
                    DOSE 3=  AIR
                    DOSE 4=   SILICON

HORIZ. RANGE      DOSE 1    DOSE 2    DOSE 3    DOSE 4
 1.000E+01 M   *  8.91E+05 1.16E+06 8.12E+05 1.05E+06
 5.000E+01 M   *  5.43E+04 7.17E+04 4.93E+04 6.46E+04
 1.000E+02 M   *  3.18E+05 4.36E+05 2.87E+05 3.90E+05
 2.000E+02 M   *  6.35E+05 9.51E+05 5.63E+05 8.35E+05
 4.000E+02 M      2.11E+03 3.63E+03 1.83E+03 3.08E+03
 6.000E+02 M      4.50E+02 7.50E+02 3.92E+02 6.42E+02
 8.000E+02 M      1.11E+02 1.76E+02 9.73E+01 1.52E+02
 1.000E+03 M      3.10E+01 4.68E+01 2.73E+01 4.10E+01
 1.200E+03 M      9.53E+00 1.38E+01 8.43E+00 1.22E+01
 1.400E+03 M      3.16E+00 4.44E+00 2.80E+00 3.96E+00

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